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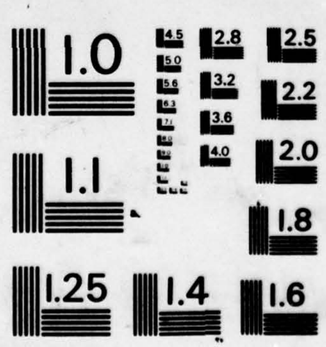

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INERTIAL NAVIGATION SYSTEMS TESTING HANDBOOK

AFFTC

JULY 1976

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This handbook describes the methods being used in testing an inertial navigation system at the Air Force Flight Test Center (AFFTC). Future technological advances, deviations for peculiar characteristics of individual test programs, and cost constraints may necessitate other methods being used in some cases. A background on inertial navigation systems, flight testing, and documentation of computer software developed for post-flight reduction of data is presented.

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PREFACE

This handbook presents the methods used in testing an inertial navigation system at the Air Force Flight Test Center (AFFTC), Edwards AFB, California. The work was done under the authority of the Improved Navigation Systems Testing and Analysis Study Plan.

The format of this handbook was chosen to make it usable to project engineers of the Systems Engineering Branch at the AFFTC. As such, information is presented to give a novice in the field of inertial navigation system evaluation sufficient background and knowledge to perform an accurate evaluation of inertial navigation systems.

The authors wish to acknowledge the following individuals who were instrumental in the preparation of this handbook: Mr B. Lyle Schofield, Chief, Flight Test Technology Branch, for guidance and editorial comments, and Mr William Taylor, Mathematician, for assisting in the development of the computer software.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

The purpose of this document is to provide the Flight Test Engineer with a procedural document for the planning and conduct of a flight test evaluation of any inertial navigation system (INS). Included in this document is a description of the types of inertial navigators that will be tested at the Flight Test Center in the foreseeable future and guidelines on how to plan the testing from an initial estimate of the required flying hours to the writing of the final report. The detailed test procedures required to collect the necessary data are covered including sample flight cards. Data collection and analysis are discussed using actual test data to substantiate the techniques addressed. Methods of presenting the data in various reports are discussed.

The appendixes contain information on the two computer programs used to analyze the test data, NAVAN and CEPLOT. The program description and users guide is contained in appendixes A and B, with check cases in appendix C.

THEORY OF OPERATION

Inertial space is defined as that space where Newton's laws of motion apply. Inertial navigation is based upon measurements made with respect to inertial space. An inertial system[1] determines the displacement of the carrying vehicle from its starting point by measuring the accelerations of the vehicle relative to the earth and integrating the accelerations with respect to time.

The basic measuring instrument of an inertial navigation system is the accelerometer, an instrument which measures acceleration along a single axis. Inside the accelerometer is a pendulous mass which is free to rotate about a pivot axis in the instrument. There is an electric pickoff which converts the rotation of the mass about the pivot axis to an output signal. The output signal is fed to a high gain amplifier and the output of the amplifier is connected back to a torquing coil on the accelerometer. When an acceleration is present, a current is sent back to the torquer which is precisely the amount required to restore the mass to its initial position. The accelerometer torquer can be restored with a direct current or it can be restored with pulses. Most modern systems use pulse restoration because of the ease in which the accelerometer output can be processed by a digital computer. A simplified block diagram is shown in Figure 1.

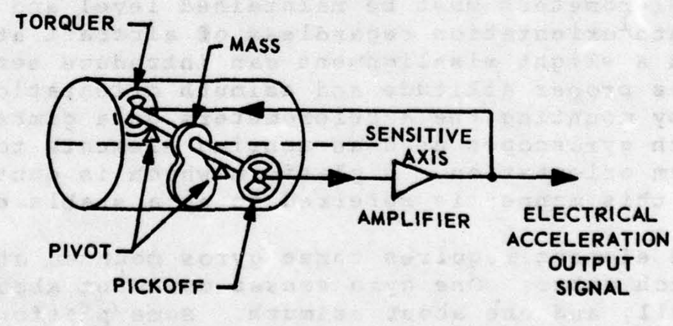

Figure 1 Accelerometer

The current fed to the torquer is proportional to the measured acceleration and provides the electrical signal which is fed to the navigation computer. The computer integrates the acceleration to produce velocity and then integrates the velocity to compute distance. If two

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[1] Defined in glossary

accelerometers are mounted at right angles to each other on a platform which is maintained level with respect to the earth and if one of the accelerometers is directed to true North, it is possible to determine the distance that the platform traveled in the North-South and East-West directions. If the platform is "told" where it is initially, it can determine where it is on the face of the earth at all times. A simple block diagram is shown in Figure 2.

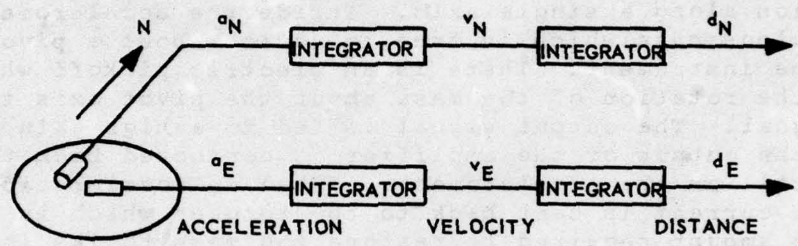

Figure 2 Accelerometers on Platform

The accelerometers must be maintained level and in proper azimuth[1] orientation regardless of aircraft attitude because even a slight misalignment can introduce serious errors. This proper attitude and azimuth orientation is maintained by mounting the accelerometers on a gimbaled platform with gyroscopes used as sensing elements to control platform orientation. A platform which is controlled by gyros in this manner is referred to as a stable element.

A stable element requires three gyros mounted at right angles to each other. One gyro senses movement about pitch, one about roll, and one about azimuth. Some platforms only require two gyros but they are two degree of freedom types; i.e., they are sensitive about two axes. The stable element is mounted on gimbals to isolate it from angular motions of the aircraft. The operation of the gimbal driving system is illustrated in Figure 3.

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[1] Defined in glossary

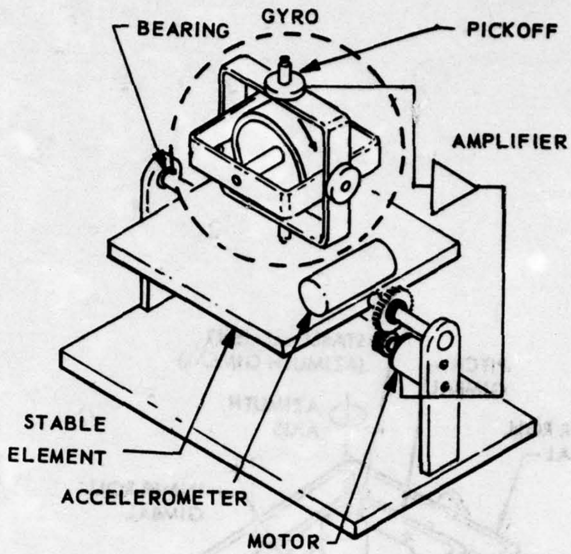

Figure 3 Simplified Single-Axis, Gyro-Stabilized Platform

The high speed spinning wheel or rotor in Figure 3 resists any motion and exhibits an important gyro characteristic called rigidity. Any movement about the bearing axis in Figure 3 generates a pickoff signal which is amplified and drives the stable element in an equal and opposite direction to the movement.

A practical inertial system requires that the platform be stabilized in all three axis of operation in order to retain its level orientation regardless of the maneuvers made by the aircraft. Figure 4 illustrates a four-gimbal platform configuration as actually used in an inertial system. The extra roll gimbal is provided to prevent the occurrence of a condition known as gimbal lock during certain aircraft maneuvers. The gimbals are oriented so that aircraft attitude and heading[1] may be sensed by measuring angles between the gimbals and the platform frame. Synchros transmit this information to the attitude indicator and other systems in the aircraft.

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[1]Defined in glossary

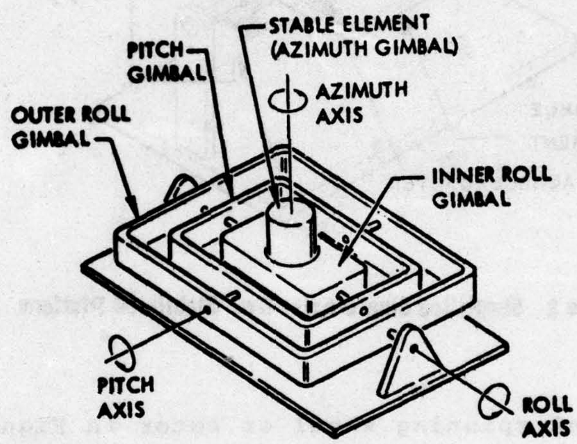


Figure 4 Four-Gimbal Platform

The inertial navigation system described up to this point is only capable of navigating on a flat non-moving earth. This is because the gyros are stablized with respect to inertial space and therefore will cause the stable element to rotate with respect to the earth as the earth rotates on its axis. This is undesirable for navigation because the accelerometers will not remain level with respect to the direction of gravity. This characteristic is illustrated in Figure 5.

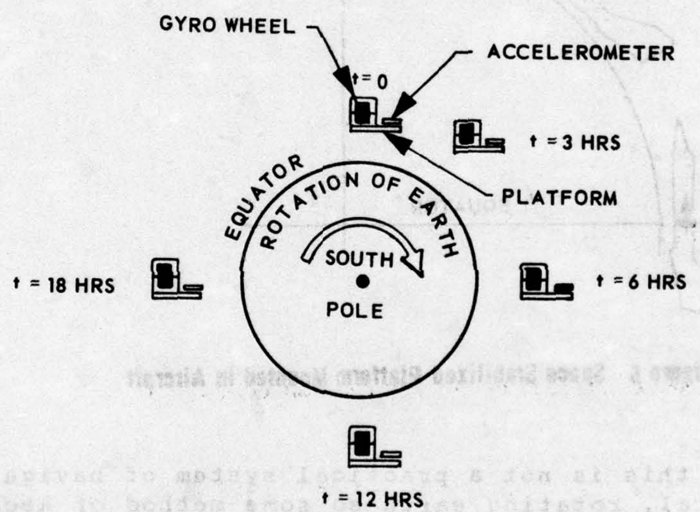


Figure 5 Space Stabilized Platform

When that stable element is mounted in an aircraft the same phenomenon occurs at the combined rates of the earth rotation plus the aircraft velocity. If the aircraft flies North so as to remove the rotation of the earth from the sensitive axis of the stable element, the aircraft "sees" a continuing pitch maneuver. At the pole, instead of the platform being level with the surface of the earth, it would now be tilted 90 degrees off level. This characteristic is illustrated in Figure 6.

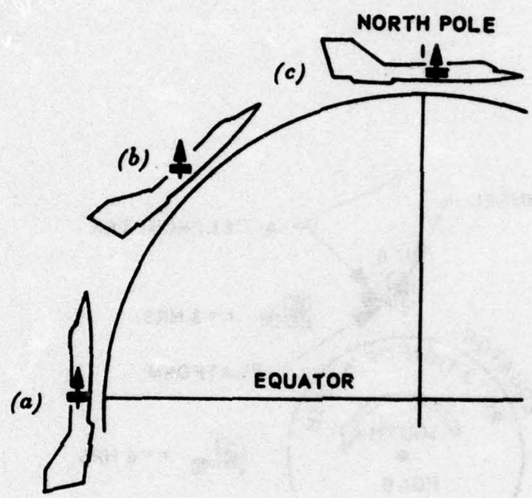


Figure 6 Space Stabilized Platform Mounted in Aircraft

Obviously this is not a practical system of navigation over a spherical, rotating earth so some method of keeping the stable element perpendicular to the earth's gravity vector is required. By applying a torque to the appropriate axis it is possible to maintain the stable element with respect to the earth and aligned in azimuth to a known reference. Gyro torque is produced by sending a current through torquer coils attached to the gyro gimbal. This torque causes the gyro to process at a right angle to the applied torque. The computer supplies the current to

properly torque the gyros. The operation of the platform with proper earth rate and vehicle rate gyro torquing is illustrated in Figure 7.

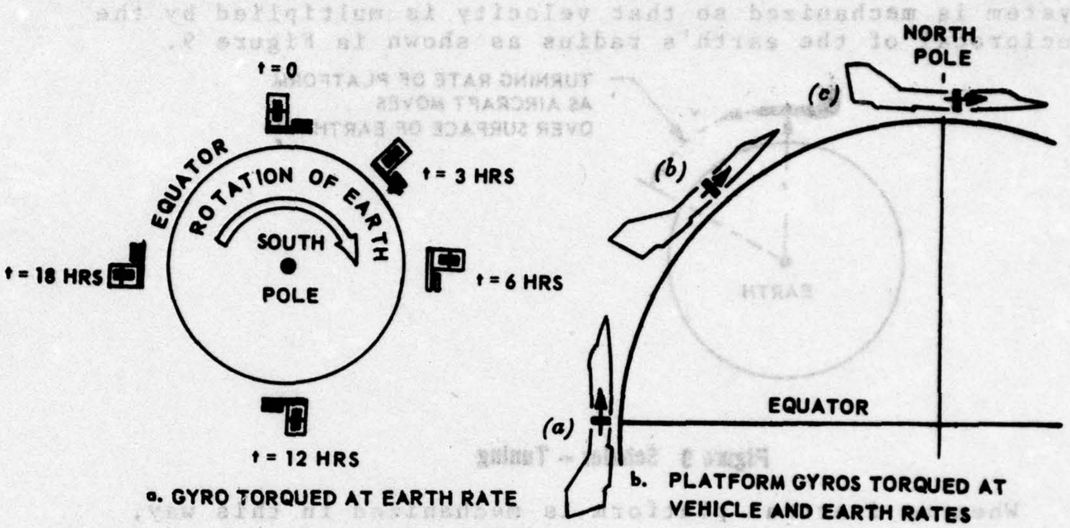


Figure 7 Earth Stabilized Platform

The torquing necessary to maintain the stable element level with respect to the gravity vector is referred to as the transport rate torque. The mechanization of this transport rate requires a computing loop which is said to be Schuler tuned. This computing loop (which is the same for each platform axis, except azimuth) is shown in Figure 8.

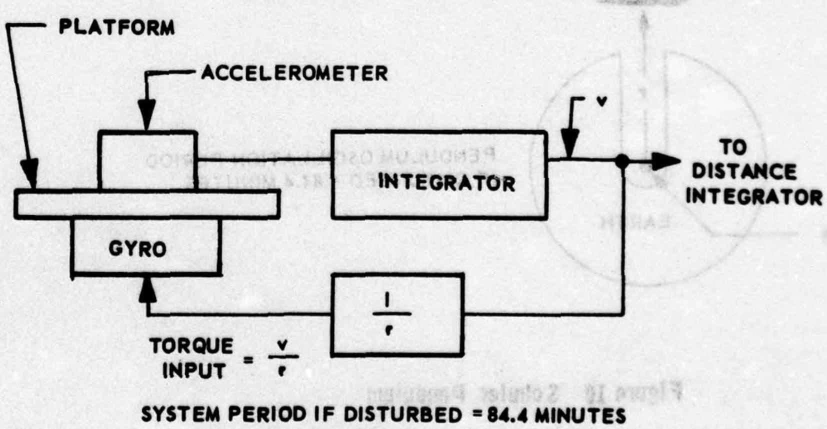


Figure 8 Schuler Computer Loop

The torquing rate necessary to maintain the platform level with respect to the surface of the earth is equal to aircraft velocity divided by the radius of the earth. The system is mechanized so that velocity is multiplied by the reciprocal of the earth's radius as shown in Figure 9.

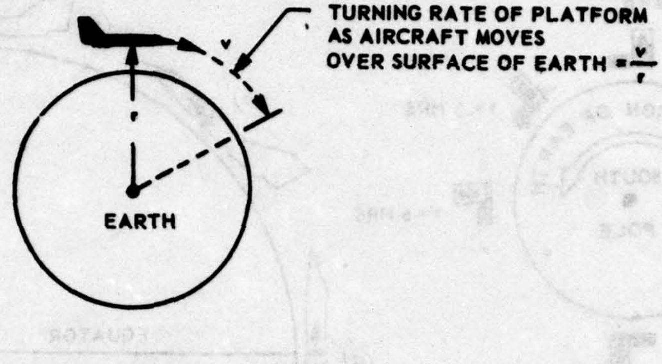


Figure 9 Schuler – Tuning

When an inertial platform is mechanized in this way, its response is similar to a pendulum with a length of 3,400 miles and a period of 84.4 minutes as shown in Figure 10. In effect, the center of gravity of the pendulum bob remains at the center of the earth and the point of suspension is at the aircraft. The point of suspension of a pendulum can be moved without causing the pendulum to oscillate so Schuler tuning allows the platform to be moved about the surface of the earth without disturbing the platform level.

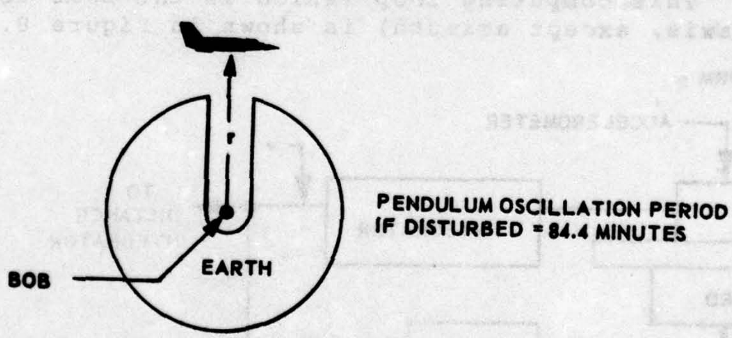


Figure 10 Schuler Pendulum

An important advantage of Schuler tuning is that many of the instrument errors are constrained from increasing with time and instead are oscillatory in their buildup. An example of a constrained acceleration error is illustrated in Figure 11. This error is due to an initial level axis misalignment of approximately one minute of arc. Note that the platform is initially tilted to the left so the accelerometer senses a component of gravity. The system "thinks" it is moving and a velocity is developed which torques the platform in the opposite direction which tends to cancel the original tilt error. The system then overshoots level and develops an acceleration error in the opposite direction. This oscillation will continue until the system is switched off or damped by a velocity input from an outside source and is referred to as a Schuler oscillation.

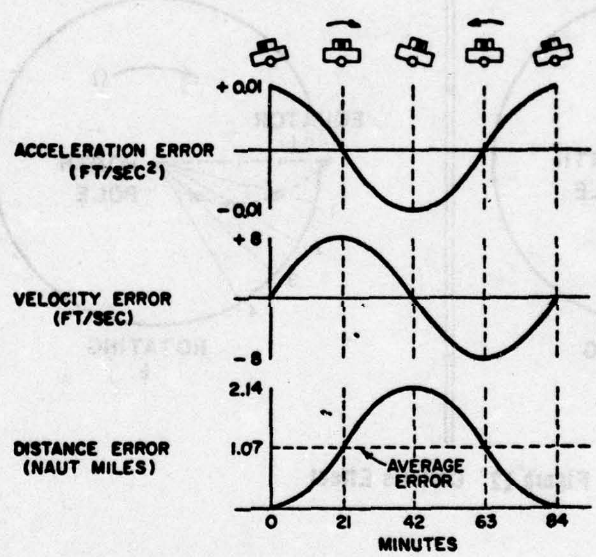


Figure 11 Constrained Acceleration Error

Correcting the platform for transport rate error allows the system to be used for navigation but not very accurately. There are three more sources of error that must be corrected before the system will navigate accurately. They are the Coriolis effect, the oblateness (flattening at the poles) of the earth, and centripetal acceleration.

The Coriolis effect exists because the earth rotates. If the earth were not rotating, a vehicle flying a straight ground course from the equator to the North pole would make a straight track as seen in Figure 12a. However, because the earth is rotating, an observer in space looking down on the earth would see that the airplane really has to fly a curved track in space in order to make the desired straight ground track over the earth (refer to Figure 12b). Relative to space, the airplane must continuously change the magnitude and direction of its tangential velocity.

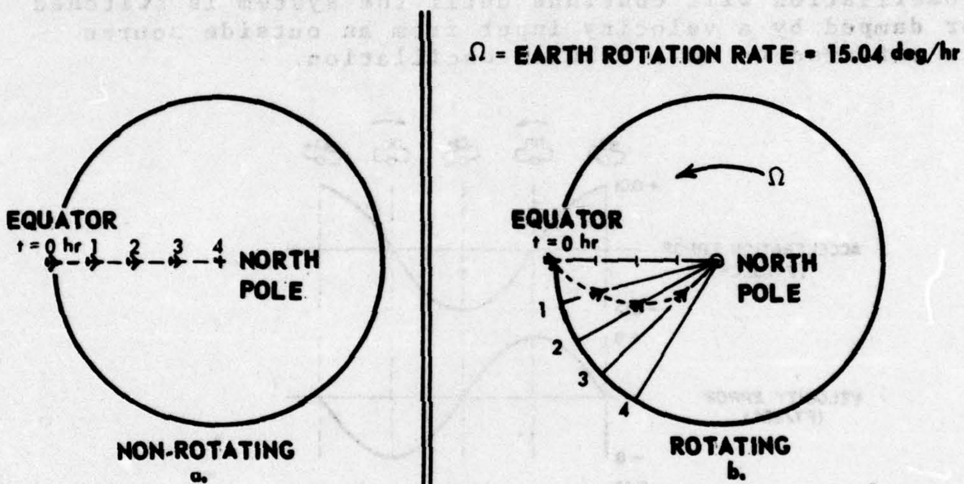


Figure 12 Coriolis Effect

Regardless of the direction of the vehicle's horizontal velocity, the Coriolis effect appears to be an acceleration to the right in the Northern Hemisphere and to the left in the Southern. Although the magnitude of the Coriolis acceleration is small, it can cause a significant navigation error when flight times are long. To compensate for the Coriolis effect, a correction factor is introduced into the output signals of the accelerometers which is equal to $2\Omega v \sin\Phi$, where Ω is equal to earth rate (15.04 deg/hr), v is velocity (N-S or E-W), and Φ is latitude.[1]

[1]Defined in glossary

The oblateness of the earth produces a spurious acceleration in the N-S accelerometer when the plumb line to the center of the earth does not exactly coincide with the true vertical as shown in Figure 13. The navigation computer must provide an earth radius correction term to the N-S accelerometer to correct for the oblateness.

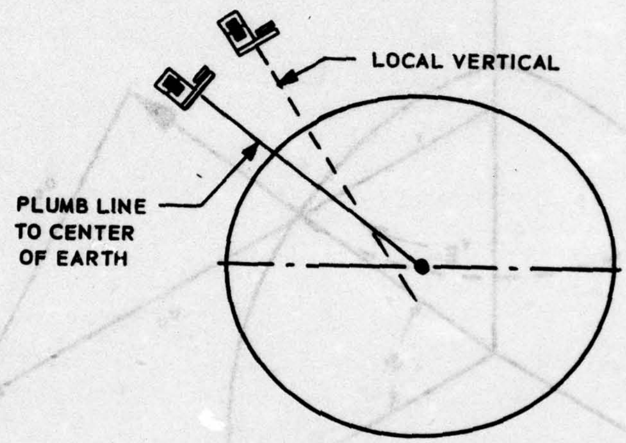
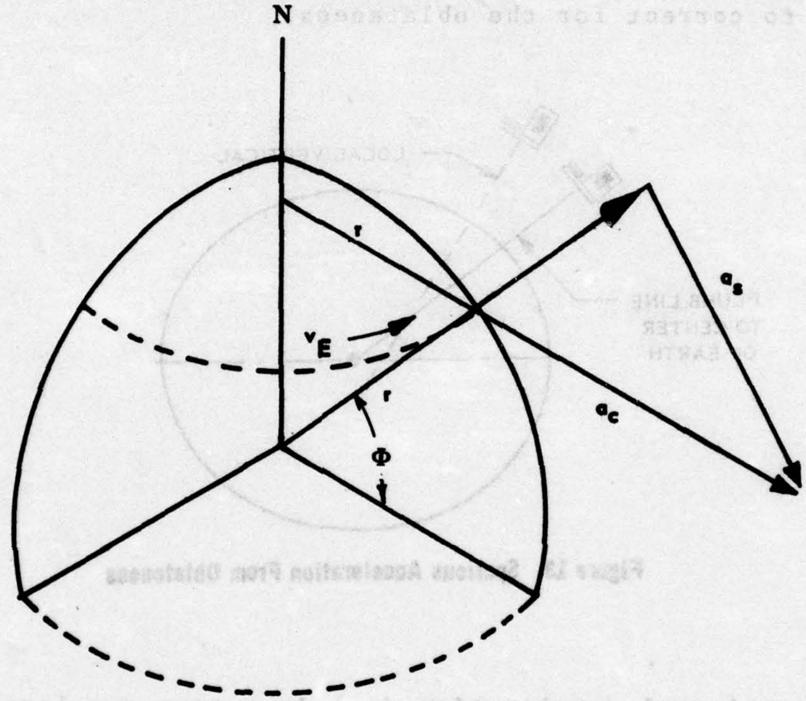


Figure 13 Spurious Acceleration From Oblateness

Centripetal acceleration (a_c) is a true acceleration with respect to inertial space that is created by a vehicle traveling about a spheroid on any course except a great circle course. Figure 14 shows an aircraft flying East along a line of constant latitude of radius r'. The center of curvature of the path of the aircraft does not pass through the center of the earth so a centripetal acceleration is generated. Since the path shown is only to the East and is in the Northern hemisphere, a South acceleration component is generated. To correct for the centripetal acceleration, a correction factor equal to $-v^2/r'\tan\Phi$ must be added to the output signal of the North-South accelerometer.



a_s = CENTRIPETAL ACCELERATION SENSED BY ACCELEROMETER

a_c = CENTRIPETAL ACCELERATION

Figure 14 Centripetal Acceleration

So far in this discussion, only the local vertical, North pointing inertial navigation system has been considered. This type of INS is referred to as a semi-analytical inertial system and is the most common system in use today. The platform gimbal structure is simple and the computer mechanization is easy. The semi-analytical system maintains the stable element perpendicular to the earth's gravity vector at all times. Accelerometer outputs are converted to velocity and distance. Velocities are used to torque the stable element to maintain the platform normal to the earth reference. The stable element is aligned in azimuth to an azimuth reference. A simple block diagram of a semi-analytical inertial system is shown in Figure 15.

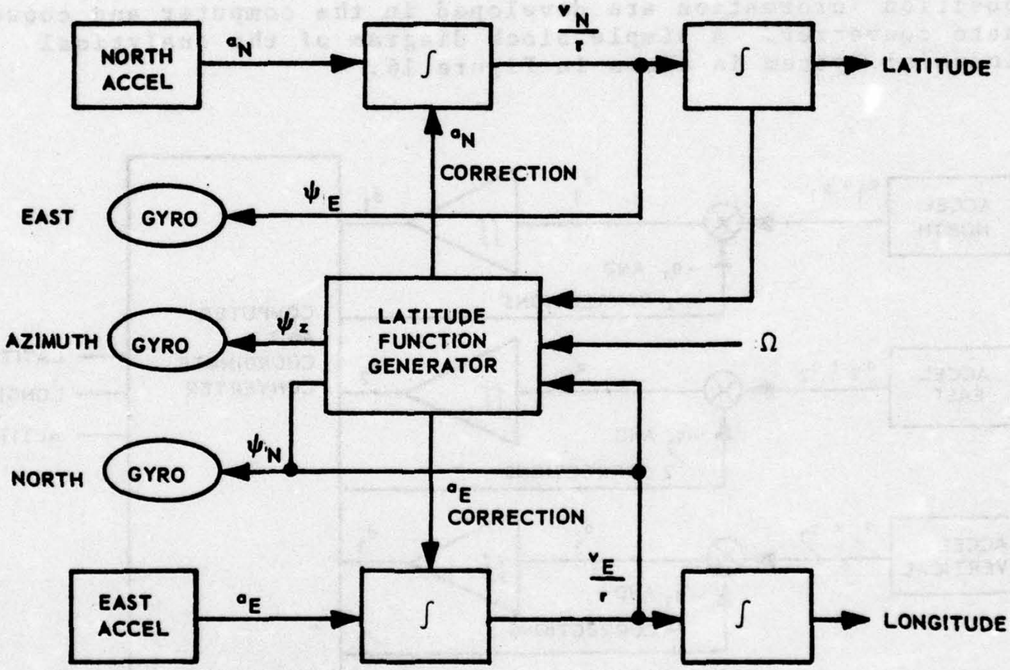


Figure 15 Semi-Analytical Inertial System

One of the major disadvantages and sources of navigation error of the semi-analytical inertial platform is the requirement to torque the gyros to maintain the platform perpendicular to the earth's gravity vector. This problem can be overcome by using an analytical navigation system which does not require gyro torquing. Because the analytical navigation platform remains fixed in space and rotates with respect to earth, the accelerometers must sense the gravity component and vehicle accelerations. For navigation purposes only the vehicle accelerations are used and the gravitational accelerations must be cancelled out. Calculating the earth's gravitational acceleration is an extremely difficult problem and requires that an enormous amount of data be stored in the computer memory. Acceleration corrections and present position information are developed in the computer and coordinate converter. A simple block diagram of the analytical inertial system is shown in Figure 16.

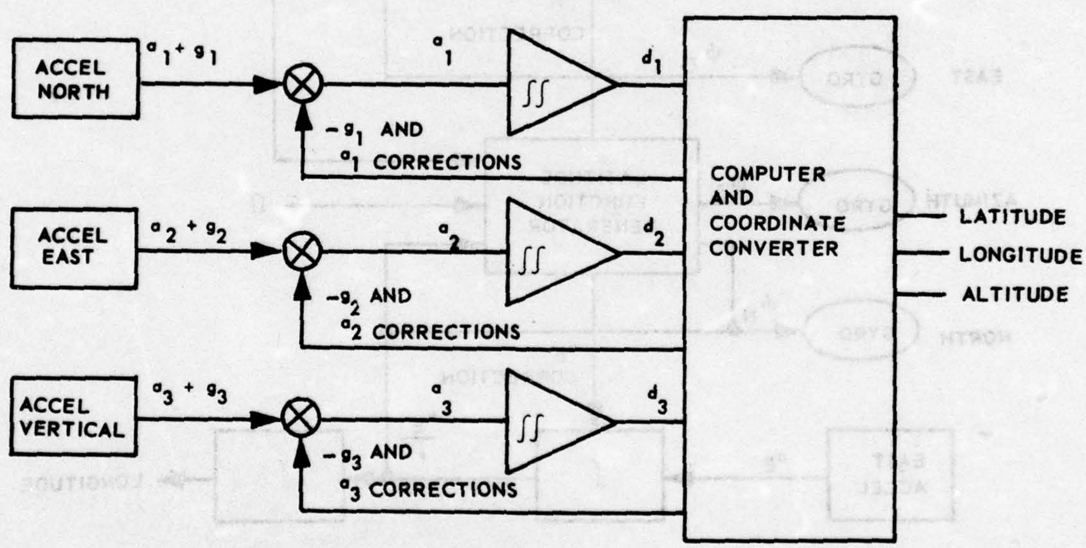


Figure 16 Analytical Inertial System

A third type of inertial navigation system is the strap-down system. As the name implies, the strap-down system does not have a conventional gimbal mounted stable element. Instead, the gyros and accelerometers are mounted directly on the vehicle frame. The computer in the strap-down system must compute the B matrix computations necessary to specify vehicular attitude with respect to an inertial reference frame. This computation is usually in direction cosine notation, direction cosines being any space vector represented by three cosines.

The coordinate converter utilizes inputs from the accelerometers and the B matrix to resolve accelerations in an inertial reference. A position computer converts inertial accelerations and altitude information to cartesian coordinates representing vehicle position in inertial space. A vector computation then provides outputs in latitude and longitude.[1]

Severe torquing requirements are placed on the gyros in a strap-down system because the gyros change attitude at the same rate as the vehicle. A simple block diagram of a strap-down inertial system is shown in Figure 17.

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[1] Defined in glossary

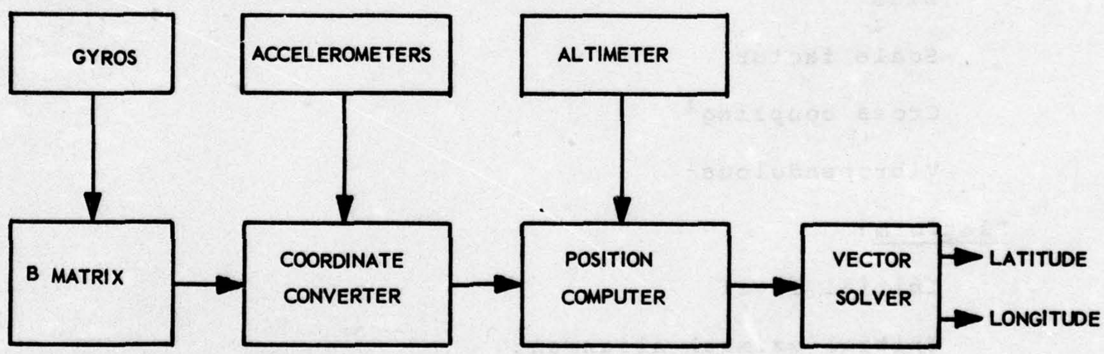


Figure 17 Strap-Down Inertial System

ERROR ANALYSIS

GENERAL

The magnitude of the errors in an inertial system may be considered as random variables at any specific flight time. In the analysis that follows, it is assumed that all errors are independent, linear, and with negligible latitude effects on Coriolis and earth rate terms.

ERROR SOURCES

Gyro:

- Bias (drift)
- Proportional bias (g sensitive)[1]
- Anisoelasticity (g^2 sensitive)[1]
- Torquing error
- Random drift
- Scale factor

Accelerometer:

- Bias
- Scale factor
- Cross coupling[1]
- Vibropendulous[1]

Platform:

- Initial level
- Initial azimuth alignment
- Servo errors
- Component non-orthogonality
  - Gyro
  - Accelerometer

[1]Defined in glossary

Computer

Round off error (register)

Truncation error (integration approximation)

Commutation error (direction cosine)

Pick off error (acceleration roundoff error)

General:

Geophysical data

Guidance equations

Target locations

The local vertical system will be studied in detail because it is a conventional system that is relatively linear and, consequently, can be handled with Laplace transformation. The understanding of the local vertical system is basic to all systems operating near the earth. As shown in Figure 18 and 19, errors can originate from various sources. For this discussion only error sources of significant magnitude (greater than 2,000 feet/hour) will be considered and all error sources will be considered to be step functions.

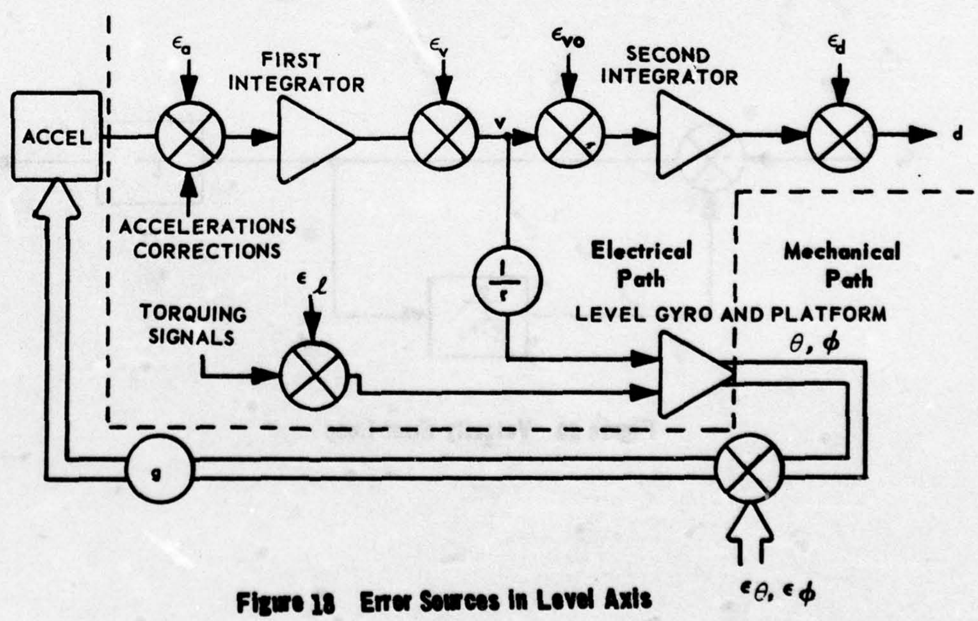


Figure 18 Error Sources in Level Axis

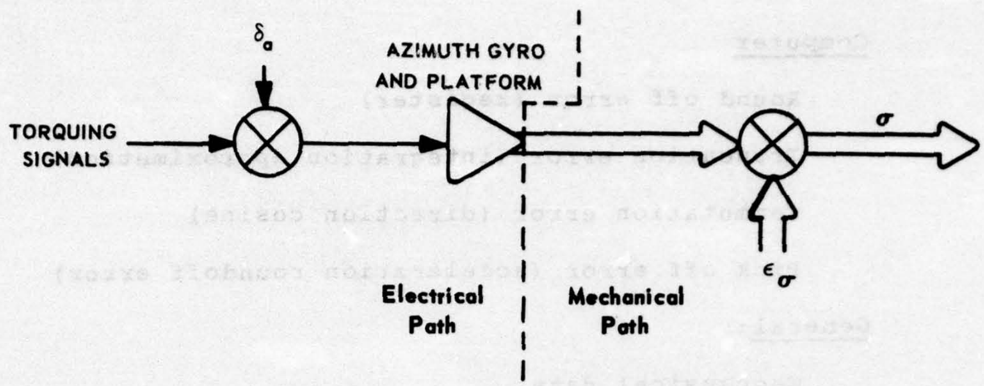


Figure 19 Error Sources in Azimuth Axis

VELOCITY ERRORS

A velocity error (ϵ_v) will cause the platform to torque out of level. The out of level platform will sense a component of gravity which it interprets as an acceleration. This signal is integrated into a velocity of opposite polarity to the initial velocity error. These velocities oscillate at the characteristic Schuler period of 84 minutes. Refer to Figure 18 where ϵ_v is a velocity error inside the Schuler loop. From Figure 18, the block diagram shown in Figure 20 can be constructed.

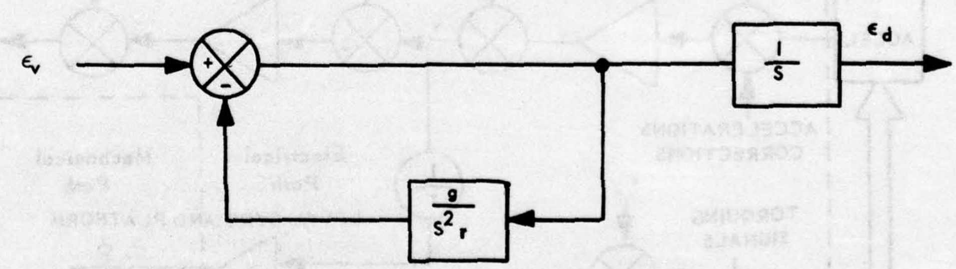


Figure 20 Velocity Error Loop

The transfer function of this error in the system is:

$$\frac{\varepsilon_d}{\varepsilon_v} = \frac{S}{S^2+\lambda^2} \qquad \lambda^2 = \frac{g}{r}$$

$$\varepsilon_d = \varepsilon_v \frac{1}{S^2+\lambda^2}$$

converting to time domain

$$\varepsilon_d = \varepsilon_v \frac{\sin\lambda t}{\lambda} \qquad \text{Equation 1}$$

ε_v = velocity error in ft/sec

ε_d = distance error in ft

g = gravity constant = 32.2 ft/sec^2

r = earth radius = 2.09×10^7 ft

t = time in seconds

Equation 1 can be converted to a more useful form.

$$\varepsilon_d = .13\varepsilon_v \sin\omega t \qquad \text{Equation 2}$$

ε_d = distance error in miles

ω = 4.46 radians/hr

t = time in hours

The velocity errors inside the Schuler loop generate position errors like the ones shown in Figure 21. Velocity errors are easily diagnosed if the inertial velocities can be compared with actual ground reference velocities.

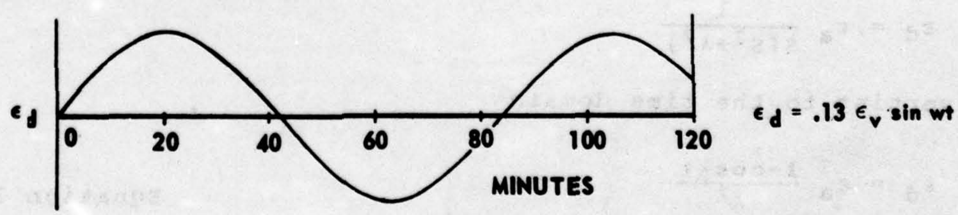


Figure 21 Effect of Velocity Error on Position Error

ACCELERATION ERRORS

Acceleration errors (ε_a) are integrated into an erroneous velocity which, thru the Schuler loop, torques the platform out of level. The out of level accelerometers sense a component of gravity which is opposite in polarity to the acceleration error. For ease of analysis, the input error is assumed to be a step function. The vector sum of the acceleration error and the gravity error oscillates at the Schuler frequency. The error in computed distance is the double integral of this acceleration error. In block diagram form, this dynamic condition is shown in Figure 22.

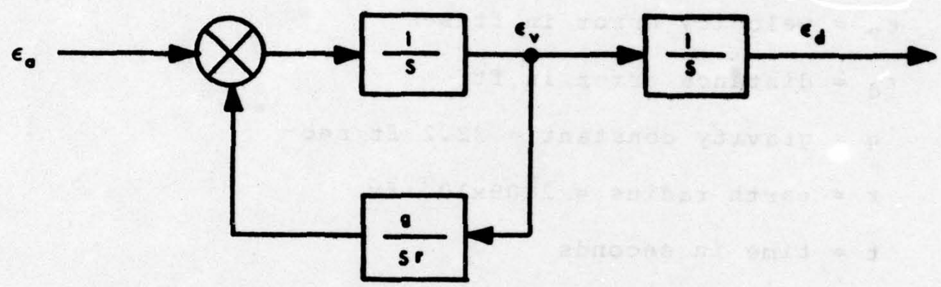


Figure 22 Acceleration Error Loop

The transfer function of this error is:

$$\frac{\varepsilon_d}{\varepsilon_a} = \frac{1}{S^2+\lambda^2}$$

Multiplying by $\frac{1}{S}$ for a step input gives

$$\varepsilon_d = \varepsilon_a \frac{1}{S(S^2+\lambda^2)}$$

Converting to the time domain

$$\varepsilon_d = \varepsilon_a \frac{1-\cos\lambda t}{\lambda^2} \qquad \text{Equation 3}$$

Equation 3 can be converted to a more useful form.

$$\varepsilon_d = 3.45\varepsilon_a(1-\cos\omega t) \qquad \text{Equation 4}$$

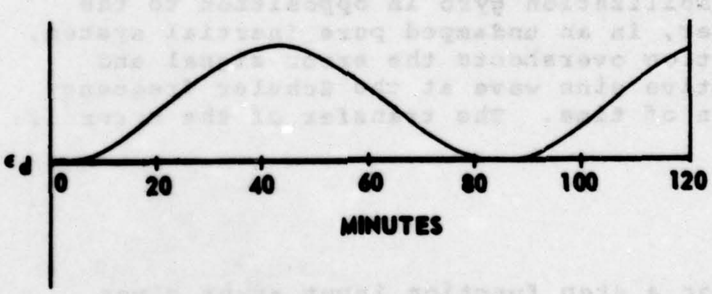
ε_d = distance error in miles

ε_a = acceleration error in ft/sec^2

ω = 4.46 radians/hour

t = time in hours

Acceleration errors generate position errors as shown in Figure 23. Note that position error does not increase with time but is constrained by the mechanization of the Schuler loop. Acceleration errors are difficult to isolate in any kind of operating environment other than a laboratory because the accelerometer outputs are rarely available external to the inertial platform for measurement by the instrumentation system. The normal method of examining the accelerometer outputs is to differentiate the velocity outputs.



$\epsilon_d = 3.45\ \epsilon_a$ (1-cos wt)

Figure 23 Effect of Acceleration Error on Position Error

LEVEL GYRO DRIFT ERRORS

Level gyro drift (ε_ℓ) is one of the most common sources of inertial error. The error is usually the result of an improper gyro bias being applied to one or both of the level axis gyros. The block diagram for the error is shown in Figure 24.

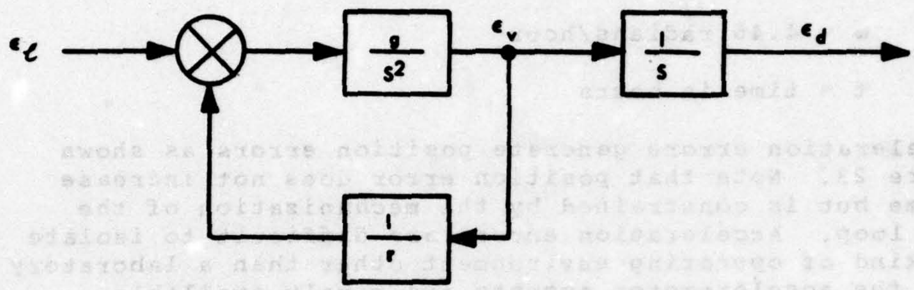


Figure 24 Level Gyro Drift Error Loop

When an error enters the system as a level gyro drift error the platform is unleveled. The accelerometers pick up a component of gravity which is integrated into velocity. Through the Schuler loop the erroneous velocity computation torques the level stabilization gyro in opposition to the error signal. However, in an undamped pure inertial system, the velocity computation overshoots the error signal and oscillates as a negative sine wave at the Schuler frequency about a ramp function of time. The transfer of the error is:

$$\frac{\varepsilon_d}{\varepsilon_\ell} = r\frac{\lambda^2}{S(S^2+\lambda^2)}$$

Multiplying by 1/S for a step function input error gives

$$\varepsilon_d = \varepsilon_\ell r\frac{\lambda^2}{S^2(S^2+\lambda^2)}$$

Converted to the time domain

$$\varepsilon_d = \varepsilon_\ell r\left(t - \frac{\sin\lambda t}{\lambda}\right) \qquad \text{Equation 5}$$

ε_d = distance error in feet

ε_ℓ = gyro drift in radians/sec

r = earth radius = 2.09×10^7 feet

t = time in seconds

Equation 5 can be converted to a more useful form by converting units.

$$\varepsilon_d = 60\varepsilon_\ell(t - 0.22\sin\omega t) \qquad \text{Equation 6}$$

ε_ℓ = gyro drift in deg/hr

t = time in hours

ω = 4.46 radians/hr

ε_d = distance error in miles

Level axis gyro drift generates position errors as shown in Figure 25.

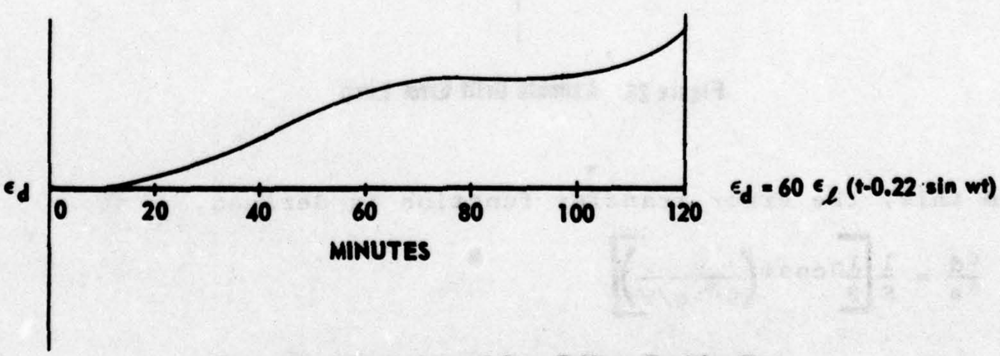


Figure 25 Effect of Level Gyro Drift on Position Error

AZIMUTH DRIFT ERRORS

The most significant cross-coupling error between axis is that of azimuth drift rate (δ_a). This error (Figure 19) is integrated by the azimuth stabilization loop resulting in an azimuth misalignment angle.[1] When misaligned, the east gyro picks up a component of the earth's rate of rotation which torques the stable element out of level. The resulting gravity error sensed by the accelerometer is integrated into velocity and torques the platform out of level opposite to the earth rate torque through the Schuler loop. The computed velocity signal overshoots and oscillates about the earth's rate torque. The block diagram for this error is shown in Figure 26.

---

[1] Defined in glossary

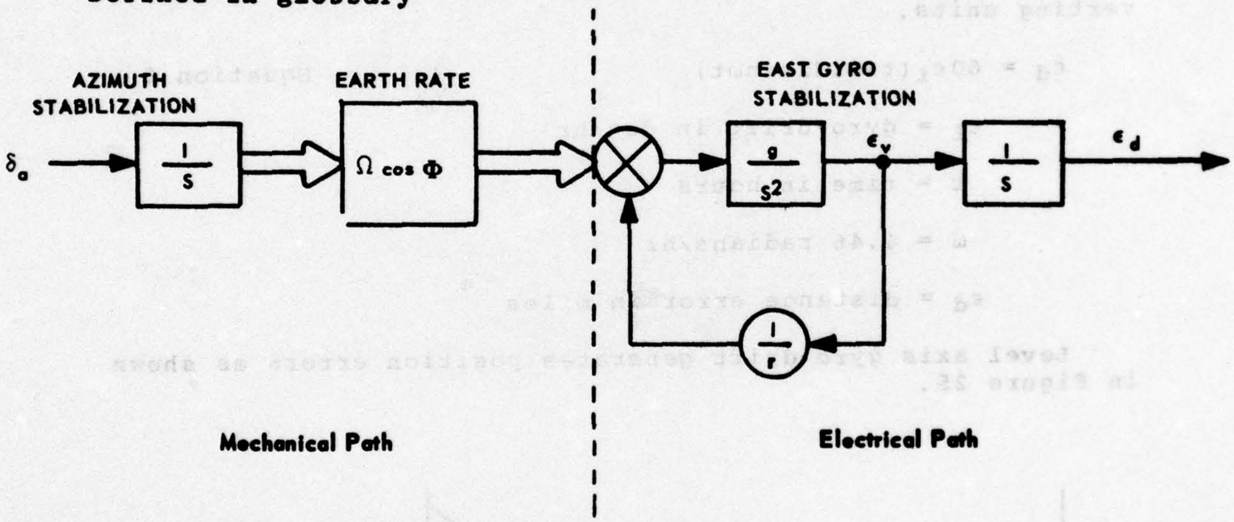


Figure 26 Azimuth Drift Error Loop

From this, the error transfer function is derived.

$$\frac{\epsilon_d}{\delta_a} = \frac{1}{S}\left[\frac{1}{S}\Omega\cos\Phi\left(\frac{g}{S^2+g/r}\right)\right]$$

Multiplying by 1/S for a step function error input gives

$$\epsilon_d = \delta_a \Omega \cos\Phi r \left(\frac{\lambda^2}{S^3 (S^2+\lambda^2)} \right)$$

Converting to the time domain

$$\epsilon_d = \delta_a \Omega \cos\Phi r \left(\frac{t}{2} - \frac{1-\cos\lambda t}{\lambda^2} \right) \qquad \text{Equation 7}$$

ϵ_d = distance error in feet

δ_a = azimuth drift rate in radians/sec

Ω = earth rotation rate = 15.04 deg/hr

Φ = local latitude

r = earth radius=2.09 x 10^7 ft

t = time in seconds

Equation 7 can be reduced to a more useful form.

$$\epsilon_d = 7.86 \cos\Phi \delta_a t^2 \qquad \text{Equation 8}$$

ϵ_d = distance error in miles

δ_a = azimuth gyro drift in deg/hr

Φ = local latitude

t = time in hours

This error is predominately in the North-South direction because the effect of earth rate upon the north gyro will be in error by the cosine of the azimuth misalignment. The cosine does not change significantly for small error angles. The distance resulting from azimuth gyro drift is shown in Figure 27. Note that the error is in the North-South axis only and that it increases in magnitude as the square of time.

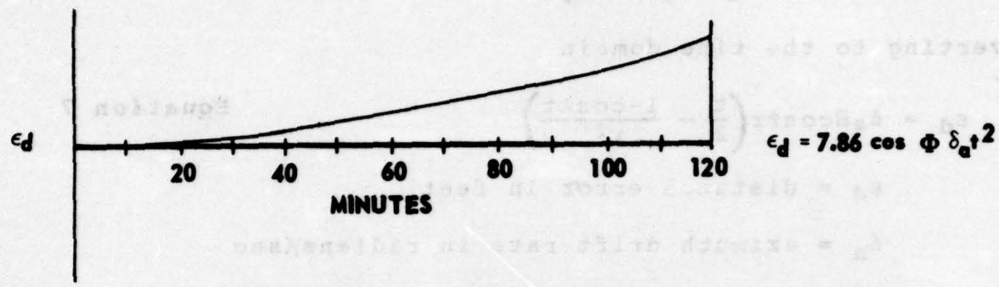


Figure 27 Effect of Azimuth Drift on Position Error

VELOCITY ERRORS OUTSIDE THE SCHULER LOOP

Velocity errors entering from outside the Schuler loop (ϵ_{VO} in Figure 18) affect the rate of the second integration and cause the distance computation error ϵ_d to have a straight line increase when the error is constant.

INITIAL AZIMUTH MISALIGNMENT

Initial azimuth misalignment (ϵ_σ in Figure 19) contributes to error in resolving horizonal accelerations. It also introduces errors by causing the east gyro to sense earth rate.

INITIAL LEVEL MISALIGNMENT

In addition to accelerometer null uncertainties, there may be acceleration errors because of initial level misalignment errors (ϵ_θ, ϵ_ϕ in Figure 18) due to a dead band in the servo null of the platform gimbals. This error may be written as $\epsilon_a = g\sin\epsilon_\theta$ for a level misalignment in the pitch axis where g is the acceleration due to gravity in feet-per-second-per-second and ϵ_θ is the level misalignment of the pitch axis in radians. An error in the roll axis would be written as $\epsilon_a = g\sin\epsilon_\phi$.

TEST PLANNING

ADVANCE PLANNING

When the Flight Test Center is assigned as the Responsible Test Organization for any flight testing, a certain amount of advance planning is required. If the testing is to include an inertial system, an estimate of the number of flights and flying hours required to evaluate the system will be made.

The evaluation of the INS should be divided into two separate areas, accuracy and operational suitability. To predict the accuracy of an INS with an 85 percent confidence in the validity of that prediction requires a minimum of eight dedicated and valid flights on an instrumented aircraft for each alignment mode that has an accuracy specification written against it. The eight flights per alignment mode produce a Circular Error Probable[1] (CEP) prediction. Each flight length should be in excess of one Schuler period of one hour and 24 minutes. It is desirable to exceed two Schuler periods but that is not a requirement as long as the test flight lengths are compatible with the operational mission requirements of the aircraft. Operational suitability does not require dedicated test flights but adds 0.1 flying hours to every test flight.

To determine the inflight accuracy of an inertial system with a reasonable confidence level requires an on-board instrumentation system. The inertial parameters must be measured with a degree of precision that will allow testing to the defined requirements. The specific parameters to be measured for each inertial system will change somewhat from aircraft to aircraft but the general requirements do not change. The following list is the general measurements required for quantitatively testing an inertial system:

Inertial longitude
Inertial latitude
Inertial elevation
Inertial ground speed
Inertial ground track
Inertial velocity in N-S direction
Inertial velocity in E-W direction
Inertial vertical velocity

[1] Defined in glossary

Inertial wander angle
Inertial roll angle
Inertial pitch angle
Inertially computed magnetic variation
Inertially computed wind speed
Inertially computed wind direction
True airspeed input to inertial system
Magnetic[1] heading input to inertial system
Pressure altitude input to inertial system
Roll angle from auxiliary reference system
Pitch angle from auxiliary reference system
Magnetic heading from auxiliary reference system
Radar range
Radar bearing
TACAN range
TACAN bearing
Present position update command
Enter visual fix command
Aircraft angle of attack
Aircraft vertical acceleration at the center of gravity
Tone and event command

As soon as the location of the test facilities are defined at Edwards AFB, the systems test engineer should determine if the alignment coordinates and local magnetic variation is available for all of the proposed parking spots for the test aircraft. The local magnetic variation should be remeasured for each of the parking spots approximately every four years. This is because the magnetic variation in the Edwards AFB area changes at the rate of 1.5 minutes per year or 0.1 degrees every four years.

DETAILED PLANNING

Test Information Sheet (TIS):

After the preliminary test planning has been calculated, documented, and provided to the project engineer, the systems analyst (test engineer responsible for the analysis of the flight test data on the inertial system) should begin the detailed test planning. This planning is documented on a for inclusion in the test plan. The TIS form shown in Figure 28 has the major topics identified that are to be included in the documentation. These topics will be discussed individually in the following paragraphs:

[1] Defined in glossary

AFFTC TEST INFORMATION SHEET (TIS) (TEST PROGRAM)		DATE	PAGE OF PAGES
TITLE OF TEST **Inertial Navigation System Tests**		VEHICLE TYPE	TIS NUMBER
		EFFECTIVITY	REVISION
TIS TYPE ☐ PLAN ☐ PROCEDURAL	LOCATION OF TEST **Edwards AFB**	TESTING ACTIVITY **AFFTC**	HAZARDOUS/UNUSUAL TEST **No**

1.0 References

2.0 Test Item Description

3.0 Test Objectives

4.0 Success Criteria

5.0 Data Requirements

6.0 Test Procedures

7.0 Support Requirements

AFFTC FORM JUN 73 261 REPLACES AFFTC FORM 0-120, JUN 73, WHICH WILL BE USED.

Figure 28 Test Information Sheet

1.0 References: The first reference to be listed is the Air Force management document that is used to generate the aircraft or system contract. This document will detail the operational requirements that were intended to be satisfied. The next reference document will be the contractors system specification document. In this document, the contractor tries to quantify the operational requirements contracted for by the Air Force. The third reference document should be the detailed INS specification document published by the manufacturer of the INS. The fourth reference document should be the aircraft flight manual showing how to operate the INS. All of the maintenance documents used at the AFFTC to maintain the system should also be referenced.

2.0 Test Item Description: The description should not be of an INS in general but rather, what makes up this particular inertial system. Identify all of the aircraft components that are considered to be a part of the inertial system and will be included in the evaluation. Describe the alignment modes and operating modes. Briefly discuss any software that will be considered a part of the INS.

3.0 Test Objective: The test objective will be much the same for any INS evaluated. It will normally be "To determine the operational accuracy and usability of the Inertial Navigation System."

4.0 Success Criteria: The accuracy portion of the testing will be complete when sufficient test points are available to give a reasonable estimate of the INS accuracy. This estimate requires a minimum of eight valid data flights for each mode of operation and/or alignment. If any development changes are made to the hardware or software after the accuracy testing has been accomplished and if those changes could affect system accuracy, then sufficient retesting must be accomplished to demonstrate the impact of the change. Operational suitability testing will continue on a ride-along basis until the end of the test program.

5.0 Data Requirements: The end point data for all valid data flights is normally presented on a circular error plot with the vertical axis showing North-South error and the horizontal axis showing East-West error. The accuracy requirement is shown as a circle whose radius is equal to the specification CEP. Each flight terminal error point is normalized to the time duration of the specification and plotted. The average value of all the plotted points is calculated and plotted. The predicted CEP based on the test data is derived and plotted according to a formula that is

used by the AFFTC to evaluate all inertial systems tested at the Center. If the contractor uses a different technique for calculating CEP, that value should also be calculated and plotted.

If in-flight accuracy data are obtained, the data will be presented as an error time-history plot for each flight. Multiple flights in an alignment mode will be used to generate a CEP time-history plot. A separate CEP plot will be made for each alignment mode evaluated. An 85 percent confidence limit should be shown on each CEP time-history plot along with the specification for the INS.

Ground test data should be obtained and compared with the specifications called out in the maintenance technical publications for ground checking the platform. The relationship of ground accuracy and in-flight accuracy should be documented.

6.0 Test Procedures: This section will contain the overall test plans for the inertial platform. It should be as detailed as possible at the time the TIS is prepared and should start with ground testing and conclude with in-flight testing. Specific test techniques will be discussed for various types of testing later in this report.

7.0 Support Requirements: This section should detail all of the services furnished by organizations other than Systems Engineering. Included should be a list of the instrumentation parameters, range support, data support, radar tracking support, and photographic support.

Data Collection:

Collection of the INS data is the responsibility of the systems test engineer assigned to evaluate the INS system. The test engineer must plan in great detail how the test points are to be flown. After he has planned how to obtain the test points on each flight, he should make up the test cards for this part of the testing. He should discuss the test cards with the Project Engineer to make sure that all test points and cards are practical. A test support summary should be written up for each test flight detailing flight speed and length, photo and/or safety chase requirements, radar tracking requirements, photo theodolite tracking requirements and instrumentation support requirements. This planning must be complete before scheduling a test mission (approximately two weeks before flight).

Instrumentation support requirements planning should produce a prioritized list of parameters which must be operating for data analysis on each flight. The list should include measurements of aircraft configurations, aircraft attitude, and aircraft dynamic conditions so that it can be determined what the dynamic conditions of flight were at specific times during the flight. The planning should also identify any special instrumentation pre-flight and post flight requirements.

A complete history will be kept on each inertial platform in the test program. When an inertial platform is initially assigned to the test program, a platform history log like the one shown in Figure 29 is initiated. Every hour of platform operation during the test program should be documented, regardless of the reason for the operation. This requires the cooperation of the ground maintenance personnel. Control procedures must be worked out with the maintenance personnel and the project engineer on each test program to make sure that none of the data is lost.

The accuracy of the INS platform boresight should be determined and documented at some time during the test program. This is necessary to prove that INS data obtained on any particular aircraft is valid and does represent what can be expected out of the using command aircraft providing they are also within tolerance on the boresight alignment. The boresight check should be made as early as possible in the test cycle. If the platform is out of tolerance, all data obtained prior to correcting the boresight is invalid and can not be used to demonstrate the system capability.

Inertial data are obtained during all-weather testing and should be analyzed. However, that test requirement should be considered as being in addition to the baseline data that will be obtained at Edwards AFB. The reason for this is that if there are any observable differences between the data because of the difference in environment, there must be enough data at each condition to prove and present the difference. Keep in mind that the all-weather test aircraft will be tested at a remote site so it may be impossible to analyze the data in a very timely manner. In fact, there is a good probability that the test engineers that accompany the all-weather test aircraft to a remote test site will not have the background to analyze the INS test data. Their primary responsibility is to conduct the test, not to analyze subsystem performance.

INERTIAL PLATFORM HISTORY LOG															PLATFORM SERIAL NO. XXXX		
DATE	EVENT (1)	HOUR METER START	ALIGN MODE	ALIGN TIME	ALIGN TEMP	ALIGN HDG (2)	MAG VAR (3)	ALIGN COORDINATES		NAV MODE	(4) SHUT-DOWN COORDINATES		SHUT-DOWN VEL.	HOUR METER END	NAV TIME (5)	P/P UPDTS	REMARKS
								LATITUDE	LONGITUDE		LATITUDE	LONGITUDE					

(1) Flight number, drift run, lab calibration, etc...

(2) Aircraft true heading during ground alignment

(3) System computed magnetic variation at completion of alignment

(4) If shutdown location is different from alignment location, note shutdown location coordinates in REMARKS section

(5) Time from selection of navigation mode to shutdown of INS to be extracted from flight cards.

AFSC FORM JAN 68 1882 PREVIOUS EDITION OF THIS FORM MAY BE USED. GENERAL PURPOSE WORK SHEET (17" X 11") AFSC (AAFB)

Figure 29 Inertial Platform History Log

Ground Testing:

Sufficient ground testing should be accomplished to establish the relationship of the ground accuracy to the in-flight accuracy and to validate the ground maintenance procedures called out in the T.O.'s. This testing should be accomplished by the engineer responsible for analyzing the INS performance but could be accomplished by others. As an example, maintenance will often perform a ground drift run to check out the system. The engineer should obtain and use the data from the drift run.

The length of a ground drift run should never be less than 84 minutes. A minimum of eight ground drift runs should be made for each alignment mode during the course of the test program to obtain a confidence level of at least 85 percent in the validity of the data. If in-flight accuracy data are obtained, it is a good policy to obtain drift run data before and after the flight using the same alignment mode as for the flight. However, the platform should be allowed to cool down to ambient temperature between shutdown and the next alignment and that requires a minimum of 12 hours. It is also preferable to start the alignment on a different heading than the shutdown heading. This will insure that the platform will have a reasonable amount of shutdown error to correct during alignment. Aligning on various headings helps to identify the effectiveness of the heading bias correction constant. A sample INS ground drift run card is shown in Figure 30.

Operational Testing:

For operational testing, the data that will be plotted is normalized endpoint data. The inertial platform history log shown in Figure 29 has all of the data required to produce endpoint data plots. The flight data on that log will be obtained by the systems test engineer from the flight crew at postflight debrief. Sample alignment and shutdown cards are shown in Figures 31 and 32. These cards should be prepared by the systems test engineer and given to the project engineer at least one day prior to flight. The REMARKS entry shown on Figure 31 is to document the wind conditions during the alignment, any observable vibration or movement of the aircraft during the alignment, and whether the power source was switched from ground power to aircraft power during the alignment.

INS GROUND DRIFT RUN - CARD 1

Date	A/C S/N	INS Platform S/N
Align	Align Latitude	Align Longitude
Align Heading	Align Mag Var	Hour Meter Start/Stop

1. Set timer to zero ________
2. Start timer and alignment together ________
3. Time when heat light out (if available) ________
4. Time when fully aligned ________
5. Time when NAV selected ________
6. System magnetic heading ________
7. System magnetic variation ________
8. Document the time, latitude, longitude, and velocity in five minute intervals (Card 2) ________

INS GROUND DRIFT RUN - CARD 2

Elapsed Time	Latitude	Longitude	$V_{X(N-S)}$	$V_{Y(E-W)}$	V_Z

Figure 30 INS Ground Drift Run Test Cards (Cards 1 and 2)

INERTIAL ALIGNMENT

1. Align mode________________
2. Function switch to align Time________________
3. Enter coordinates and reset
4. Heat light out Time________________
5. Record outside air temperature

   Temp________________
6. Alignment complete Time________________
7. System heading

   HDG________________
8. System magnetic variation

   MAG VAR________________
9. Select NAV position Time________________
10. Remarks________________________________

Figure 31 Inertial Alignment Test Card

INERTIAL SHUTDOWN

1. Shutdown coordinates

   Latitude________ Longitude________ Elev________
2. System heading

   Hdg________
3. System magnetic variation

   MAG VAR________
4. System computed range and bearing to shutdown coordinates

   Rng________ Bearing________
5. Record inertial system coordinates

   Latitude________ Longitude________ Elev________
6. Record inertial system velocity

   GND SPD________

   V_X________ V_Y________ V_Z________
7. Turn the inertial system off

   Time________

Figure 32 Inertial Shutdown Test Card

The flight data will be presented on data plots that reflect the alignment mode. To demonstrate any type of rapid alignment, the INS should be allowed to soak at ambient conditions for a minimum of 12 hours before starting the alignment. If the ambient soak conditions can't be met, then the platform should be aligned in the standard alignment mode (gyro-compass for a semi-analytical system).

If the inertial platform has to be shut down in flight for any reason, the data recorded before platform shutdown can not be used for endpoint accuracy data. However, if the platform is brought back up with an in-flight alignment, that data can be used as end-point data for the in-flight alignment accuracy plot providing it is possible to define the accuracy of the aircraft position versus the entered initialization coordinates.

Often during a test program it will be necessary to enter a present position correction to the INS during flight. For a non-instrumented aircraft, that almost always prevents the test engineer from using the data from that flight for anything other than a qualitative description of how well it worked. This is because it is necessary to know where the aircraft was immediately before update, how much error was in the INS at that time, and how much of the error was removed by the update in order to use the data from the flight in any kind of meaningful analysis. All of this information must be time correlated to the alignment and shutdown data.

Many inertial systems tested in recent years are bounded-error systems. This means that position and velocity parameters from the INS are mixed with data from other sources by a statistical filter to arrive at a computer estimate of position and velocity. This computer estimate is then fed back to the INS to try to keep the difference between them as small as possible. It is not really possible to isolate the INS accuracy because the accuracy of the other systems show up in the results.

Air Force accuracy requirements are nearly always specified for operational conditions. However, the contractor normally demonstrates specification compliance under a limited set of carefully controlled conditions. The initial responsibility for quantitative testing under operational conditions falls to the Flight Test Center and the systems test engineer should lay out his testing requirements with that in mind. Alignments should be made in all available modes and headings. Maneuvers should be specified on a significant number of flights that will stress the inertial platform with the same type loads expected operationally. The systems test engineer must personally prepare the

alignment and shutdown cards for each flight and review all flight cards to make sure that the flight will represent a fair operational challenge to the INS.

Inflight Accuracy Testing:

The data objective of inflight accuracy testing is to produce a single plot that compares the predicted CEP based on actual test data with the specification CEP for each alignment mode evaluated. It is desired to have a minimum of eight flights of valid data for each mode to calculate a CEP with a reasonable confidence level.

For inflight accuracy testing of current inertial systems, an instrumentation system is usually required and is always highly desirable. The system should record the on-board position coordinates with respect to a time that is correlateable to ground tracking data. As inertial accuracy flights are dedicated flights, the instrumentation recorder should be turned on and off at the desired test point intervals. An instrumentation event tone should be transmitted briefly during each recorder-on cycle so that each segment of recorded data can be individually checked for time correlation.

Range tracking accuracy is an important consideration for inertial accuracy testing. For systems that have been tested at Edwards in the past, the accuracy of the space positioning radar has been sufficient if the radar grazing angle is kept a minimum of two degrees above the horizontal plane of the radar antenna. The azimuth angle accuracy of the radar is specified as 0.2 mils which is 1.2 feet per mile of range. Figure 33 is a plot of the radar azimuth accuracy as a function of range from the tracking antenna. The minimum MSL altitude of the aircraft required to obtain this accuracy is shown at 25 mile increments. The ranging accuracy for the radar is specified as ±12 feet at all ranges.

The flight profile for an accuracy flight can be very flexible but because of the amount of data required, it is recommended that a rectangular pattern be flown along the lines of constant latitude and longitude with the length of the legs being as long as possible without exceeding the altitude and accuracy restrictions. High rate turns and pitch maneuvers should be programmed into the individual legs to task the inertial system as much as possible. The systems test engineer should monitor the test flight from whatever location that is available to him that provides him the greatest insight to the data being produced.

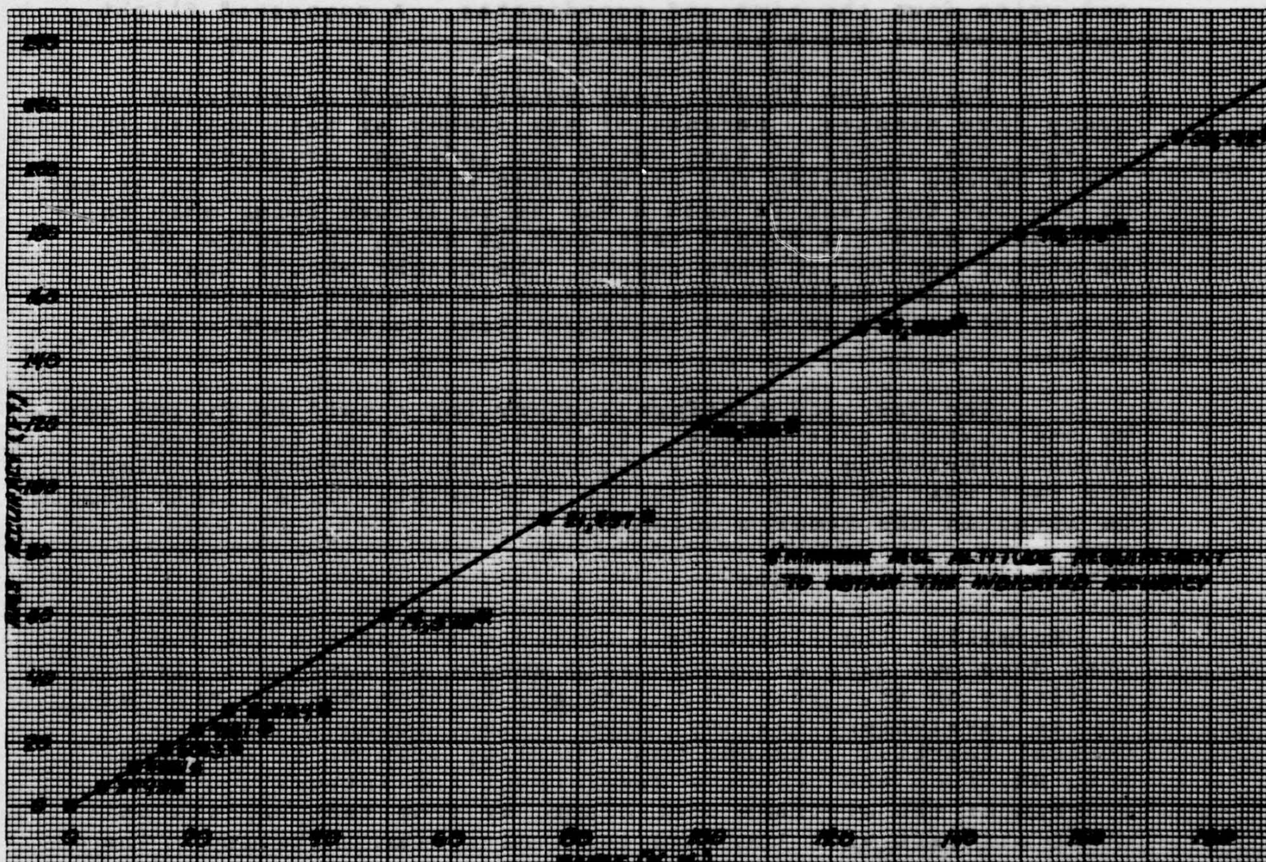


Figure 33 Space Positioning Radar Azimuth Accuracy

The data to be collected during the alignment before an inertial accuracy flight is shown in Figure 34. Observe that the data card requires the crewmember to duplicate many of the parameters being recorded by the instrumentation system. This is so that if the instrumentation system should fail, there would be sufficient data available to keep the Inertial Platform History Log current and use for end-point accuracy data. Initial alignment headings should be varied so that a minimum of two alignments will be performed in each compass quadrant.

The next data point is on the taxi-way just before the takeoff end of the runway. There is an inertial checkpoint marked on the taxi-way at both ends and the center of the runway at Edwards AFB. Photographs of the checkpoints at the ends of the runway are shown in Figures 35 and 36. When the nosewheel is over the INS checkpoint, the pilot should stop the aircraft, place an event mark on the instrumentation tape, and write down the time and coordinates. A suggested flight card format is shown in Figure 37.

During the flight, test points should be recorded every five minutes. Because of the number of test points involved, the number of test cards for inflight accuracy data could become unwieldy for an extended mission. It is important to lay out the test in such a way as to assure being able to correlate data. A sample test card is shown in Figure 38. As stated earlier in this report, the flight should last a minimum of one full Schuler cycle of 84 minutes so there should be a minimum of 17 in-flight test points five minutes apart.

The Inertial Platform History Log should be filled out by the systems test engineer from data obtained in the post-flight debriefing just as if it was a non-instrumented flight. The fact that in-flight accuracy data exists for a flight should be noted in the Remarks column.

REVIEW OF EXISTING DATA

Normally, the Flight Test Center will not test an INS that does not have a considerable amount of test data already available on it. That test data may be from the INS manufacturers development testing, from testing conducted by the Central Inertial Guidance Test Facility (CIGTF) at Holloman AFB, NM, from the avionics development and integration test program of the airframe contractor, or from test reports on other aircraft with the same inertial system installed. The systems test engineer should attempt to obtain as much of this

INERTIAL ALIGNMENT

1. Align mode___________
2. Instrumentation recorder ON
3. Function switch to align Time___________
4. Enter coordinates and reset
5. Heat light out Time___________
6. Record outside air temperature

   Temp___________
7. Alignment complete Time___________
8. System heading

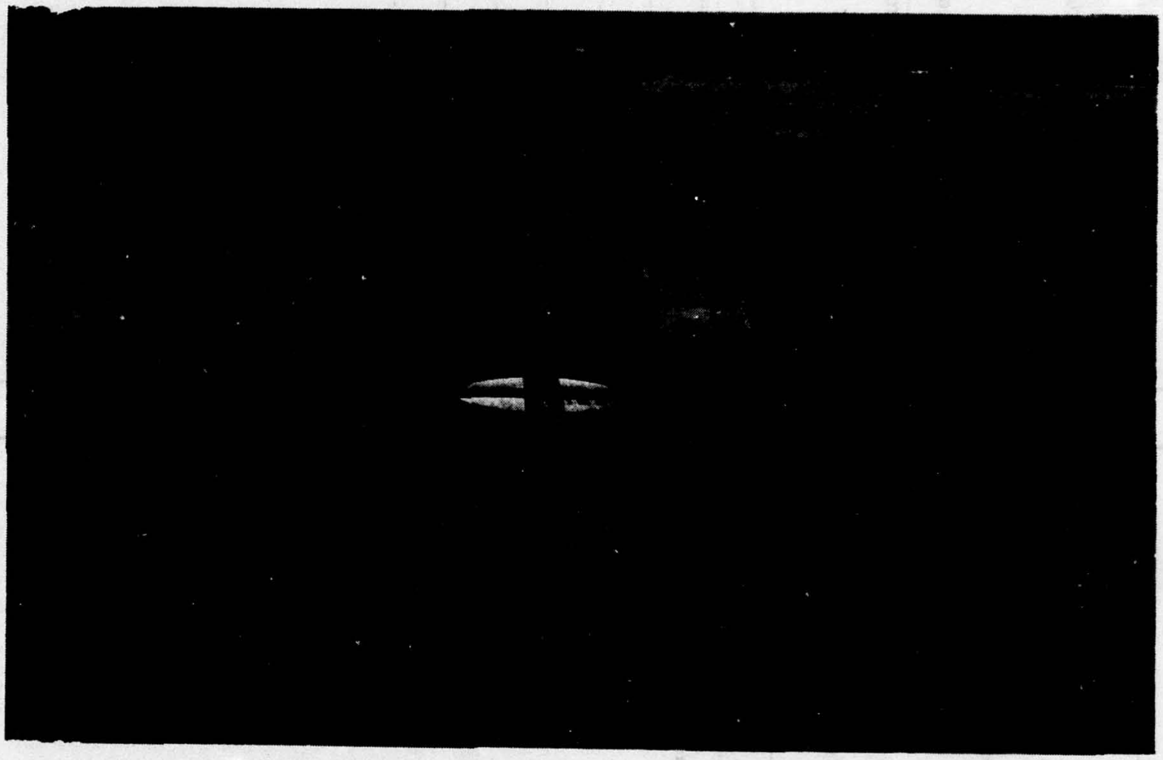
   HDG___________
9. System magnetic variation

   MAG VAR___________
10. Select NAV position Time___________
11. Instrumentation recorder OFF

Figure 34 Alignment Test Card - Instrumented Aircraft

Runway 22 at Edwards AFB

Figure 35 Inertial Accuracy Checkpoint No. 1



Runway 4 at Edwards AFB

Figure 36 Inertial Accuracy Checkpoint No. 2

INERTIAL TEST REQUIREMENTS AT TAKEOFF

1. Before reaching INS checkpoint on taxiway - RECORDS ON
2. Stop nosewheel on inertial checkpoint
3. Event Mark   Time__________
4. Record the following:

   Latitude__________   Longitude__________

   Ground Speed__________ V_X__________

   V_Y__________ V_Z__________

5. Leave records on for takeoff and phasing maneuver. Then turn RECORDS OFF.

Figure 37   Pre-Takeoff Test Card - Instrumented Aircraft

INERTIAL TEST CARD

1. At 5 minute intervals, turn instrumentation recorder ON
2. Record time
3. Wait a minimum of 15 seconds and transmit to SPORT "This is record number__________." Then activate the Tone and Event button for 3 seconds.
4. Instrumentation recorder OFF

Record No.	Time
1	
2	
3	
4	
5	
6	
7	
etc. ↓	

Figure 38   In-Flight Test Card - Instrumented Aircraft

data as possible prior to the start of the test program and be prepared to compare it with Flight Test Center data as that becomes available.

If the data from all sources does not correlate, the reason must be determined. If the data does correlate, it might be possible to reduce the number of data flights required at the Flight Test Center. However, this is a function of the confidence that the systems test engineer has in the data, so reducing the number of test flights should not be included in any of the planning.

REVIEW OF AGE AND TECHNICAL PUBLICATIONS

It is the responsibility of the systems test engineer to review all applicable technical publications and evaluate the contractor furnished support hardware to be used by Air Force maintenance personnel. The technical publications should give clear and accurate directions on operation, troubleshooting and maintenance procedures for the INS. The test equipment should provide assistance in the trouble-shooting and repair of the system.

An adequate evaluation of the AGE and technical publications requires the assistance and cooperation of the maintenance personnel assigned to the test program. The systems test engineer should try to keep the maintenance personnel fully aware of what he is trying to accomplish and the results from data already gathered. This includes showing them the data, showing how it correlates, and discretely pointing out the mistakes that maintenance personnel may make that can cause the data to be invalid. Any recommended changes in the maintenance procedures should be discussed with the maintenance personnel before submitting to the SPO.

REPORTS

The systems test engineer should plan for the reporting phase of the INS testing just as carefully as he does the rest of the test program. The reports must present all knowledge obtained as a result of the testing.

The first type of reporting that may be required of the test engineer is for Air Force Preliminary Evaluations. This type of testing is normally a quick overview where the entire aircraft is evaluated on a very small number of missions. If an INS had gross problems that would make it operationally unacceptable, this type of testing should identify it. How-

ever, the likelihood of detecting subtle design problems or accuracy problems is not very great. The data should be presented as a written summary of what was observed along with conclusions about the system operation.

During the conduct of a flight test program, the Deficiency Report (DR) is used to document and track deficiencies in the inertial system. The specific directions for using the DR form can be found in AFFTCR 80-2. Generally speaking, the DR is used to identify suspected problems to the SPO and the contractor. The systems test engineer will have the responsibility of keeping track of the DR's on the INS and whatever corrective actions that take place. A DR form is shown in Figure 39.

The progress report is a periodic management reporting tool to keep the report addressees informed on the progress of the testing and to provide an insight into any problems that exist. The progress report should summarize the INS testing for the report period, summarize the results, relate that to what has been conducted previously, and describe what remains to be accomplished. A summary of the deficiency reports submitted during the reporting period should be included. If several flights are involved, an INS flight log like the one shown in Figure 40 should be included. Note that all of the information presented on the flight log can be obtained from the Inertial Platform History Log (Figure 29).

The final report should cover everything that is known by the Test Center about the INS. The body of the report should present summarized data to substantiate conclusions about the operation of the INS. Individual flight data should be in a data appendix to the report unless specific data are required to substantiate a conclusion made in the body of the report.

AFFTC DEFICIENCY REPORT				DR NUMBER	DATE
RELATED DR/UMR NO(S).	VEHICLE TYPE	VEHICLE SERIAL NO(S).	TEST LOCATION		
MAJOR SYSTEM/WUC	SUBSYSTEM/WUC		COMPONENT PART NO./ SERIAL NO.		

DEFICIENCY
DEFICIENCY CIRCUMSTANCES/DESCRIPTION/CAUSES *(Continue on separate page if necessary.)*
LOCAL ACTION
RECOMMENDATION

RECOMMENDATION/DEFICIENCY CLASSIFICATION AND MISSION IMPACT			
☐ FUNCTIONAL ☐ OPS ☐ DESIGN ☐ MATERIEL ☐ QC ☐ MAINT ☐ RELIABILITY ☐ PSTE			
SAFETY HAZARD CODE *(MIL–STD–882)*	CORRECTION CATEGORY	POTENTIAL HAZARD	MISSION IMPACT
☐ I ☐ II ☐ III ☐ IV	☐ MANDATORY ☐ DESIRABLE	☐ LOSS ☐ VEHICLE ☐ DAMAGE ☐ SUBSYSTEM ☐ INJURY ☐ PERSONNEL	☐ PREVENTS ☐ MISSION ☐ DEGRADES ☐ MAINTENANCE ☐ RESTRICTS ☐ SYSTEM PERFORMANCE ☐ DELAYS ☐ FLIGHT/MAINTENANCE CREW EFFECTIVENESS
AMPLIFICATION/OTHER			

DR CONTACT *(Name and grade)*	ORGANIZATION *(Office Symbol)*	DUTY PHONE
PROJECT ENGINEER *(Typed/printed name and grade)*	SIGNATURE	DATE
PROJECT MANAGER *(Typed/printed name and grade)*	SIGNATURE	DATE

AFFTC FORM AUG 72 2

Figure 39 AFFTC Deficiency Report Form

INS FLIGHT LOG

DATE	FLIGHT NUMBER	TYPE ALIGNMENT	NAV TIME (min)	LATITUDE (1) ERROR (nm)	LONGITUDE (2) ERROR (nm)	RADIAL (3) ERROR (nm)	VELOCITY ERROR (kts)	DRIFT RATE (nm/hr)	REMARKS

1. Latitude error in degrees to nautical miles = latitude x 60 nm/deg
2. Longitude error in degrees to nautical miles = longitude x 60 nm/deg x cos latitude
3. Radial error = $\sqrt{\text{latitude error}^2 + \text{longitude error}^2}$ (all units nm)

AFSC FORM 185E JAN 63 PREVIOUS EDITION OF THIS FORM MAY BE USED. GENERAL PURPOSE WORK SHEET (17" X 11") AFSC (AAFB)

FIGURE 40 INS FLIGHT LOG

DATA ANALYSIS

TERMINAL ERROR PLOT

The terminal error plot shows the performance of an inertial system during the test program in terms of shutdown error for all flights. A sample plot is shown in Figure 41. Each shutdown error obtained during the test program is normalized to the time specified in the INS specification and plotted. The CEP is calculated and plotted as a circle of equal probability for each alignment mode evaluated. The title block identifies the alignment mode and the time period represented on the plot. The specification CEP is shown as a circle of radius equal to the specified value.

The data for the terminal error plot is obtained from the flight log (Figure 40). The normalized values of latitude error, longitude error and radial error are calculated by the systems test engineer and stored on a computer data card. If the test engineer judges that the data from a particular flight is invalid, it should be documented in the inertial platform history log and flight log and not punched onto data cards.

When a reasonable amount of terminal error data is available, the data is run through a CEP calculation. After the calculation is complete, the computer examines the distribution of the terminal error points with respect to the value of the calculated CEP. If the terminal error from any of the flights exceed a three-sigma value of the CEP, that flight terminal error is temporarly suppressed from the calculation and the calculation is done over. The test engineer should include all valid terminal error data that is available in the CEP calculations. New flight data should be incorporated as the inertial evaluation portion of the testing progresses.

POSITION ERROR PLOT

If inflight accuracy data are available, position error plots showing the INS accuracy as a function of elapsed time should be produced. Figure 42 shows a sample position error plot produced from actual test data. The plot displays latitude error, longitude error, and radial error as a function of elapsed time. On the plot, north latitude error and east longitude error are defined as positive. Radial error is always positive.

The AFFTC computer program that produces the position error plot is called the Navigation Analysis Program (NAVAN). In-

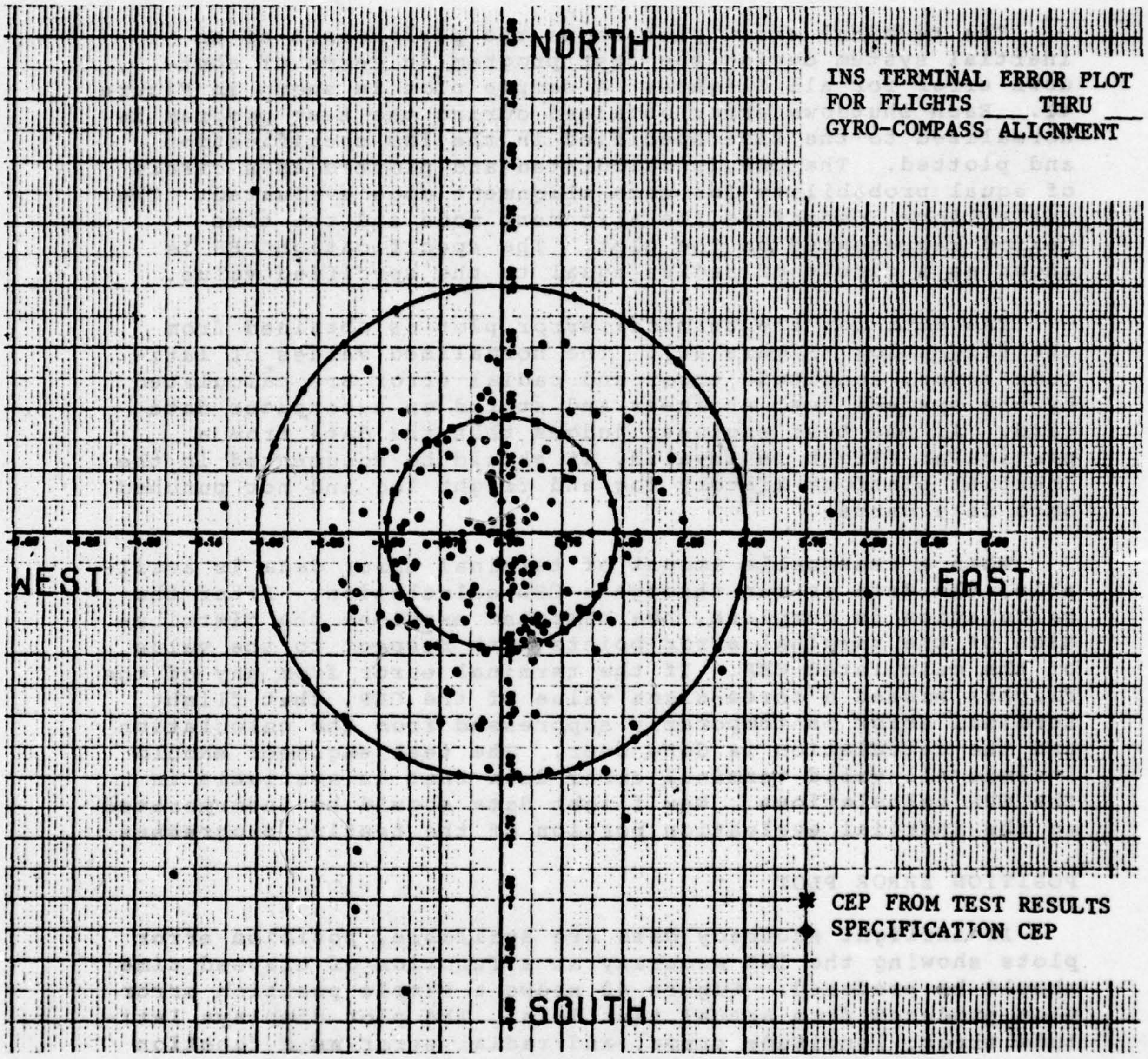


Figure 41 Terminal Error Plot

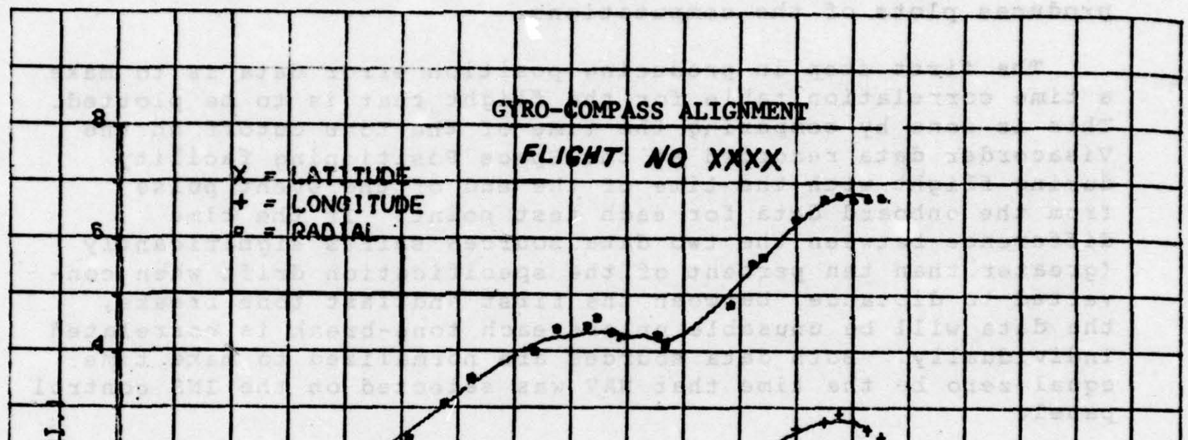


Figure 42 Position Error Plot

puts to the computer for a particular flight are a radar tracking tape of that flight from the Space Positioning Branch, an engineering units tape produced from the aircraft instrumentation raw data tape for the same flight, and card entered data for information that can't be obtained from the other two sources. The program merges the data, edits the data according to given editing specifications, writes a data file of the selected and edited parameters, performs computations, and produces plots of the computations.

The first step in producing position error data is to make a time correlation table for the flight that is to be plotted. This is done by comparing the time of the tone cutoff on the Visacorder data recorded at the Space Positioning facility during flight with the time of the end of the event pulse from the onboard data for each test point. If the time difference between the two data sources shifts significantly (greater than ten percent of the specification drift when converted to distance) between the first and last tone breaks, the data will be unusable unless each tone-break is correlated individually. Both data sources are normalized to make time equal zero be the time that NAV was selected on the INS control panel.

Next, the data is run through a smoothing routine and interpolated to make the data samples from the two sources occur at the same time. The smoothed and interpolated data is then compared to obtain the latitude error and longitude error. Radial error is calculated from the latitude and longitude errors. A listing and the plotting tape required to produce the position error plot shown in Figure 42 is then created.

CEP PLOT FROM POSITION ERROR

A single CEP plot that summarizes the results of all of the position error plots for each alignment mode is shown in Figure 43. The data used to generate the CEP curve are obtained from all of the radial error information from all of the individual accuracy flights. The 85 percent confidence limits shown in Figure 43 make the prediction that 85 percent of all future navigation errors will fall between the two curves. The specification line is the accuracy that the contractor was required to meet. This number is usually a straight-line specification for a finite time-limit. Three nautical miles per hour for the first three hours of operation is the specification that is illustrated.

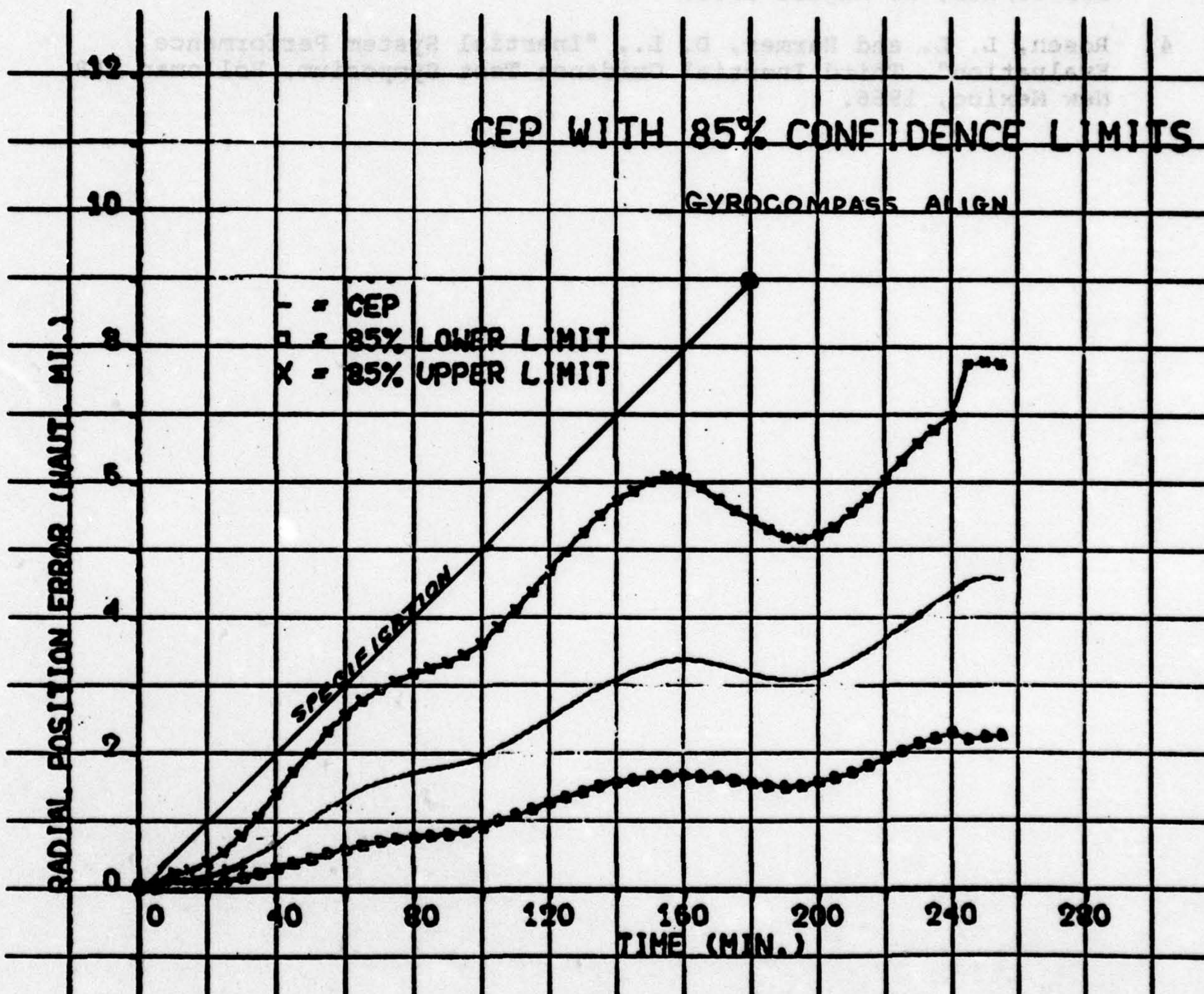


Figure 43 CEP Plot from Position Error

REFERENCES

1. Chapman and Robbins, "Minimum Variance Estimation Without Regularity Assumptions", Annals of Mathematical Statistics, Volume 22, 1951.

2. Blair, B. P., Statistical Procedures for Analysis of Weapon System Accuracy, North American Aviation, Inc., Autonetics Division, Report, EM-1188, 1957.

3. Air Standardization Coordinating Committee, "The Specification and Evaluation of the Accuracy of Inertial Navigation Systems", Air STD 53/11B, 15 August 1968.

4. Rosen, L. L. and Harmer, D. L., "Inertial System Performance Evaluation", Third Inertial Guidance Test Symposium, Holloman AFB, New Mexico, 1966.

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Pitman, George R., INERTIAL GUIDANCE, John Wiley and Sons, New York, 1962.

Britting, Kenneth R., INERTIAL NAVIGATION SYSTEM ANALYSIS, Wiley - Interscience, New York, New York, 1971.

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APPENDIX A

NAVAN Computer Program

INTRODUCTION/PROGRAM DESCRIPTION

The Navigation Analysis Program (NAVAN) is a software package developed to provide the test engineer with a method for determining the performance of inertial navigation systems. NAVAN was designed to analyze INS data obtained from flight test. NAVAN can accept data from Radar and ADAS tapes and/or punched cards. After at least three flights are merged, the mean, median, R50, R90, CEP and confidence limits are calculated and data is plotted.

Data editing of the Radar data is done by checking radar velocity against the maximum value selected by the engineer (default = 900 ft/sec). If the velocity exceeds this value the data associated with this time is replaced with the data at the last inbound time. Replaced data is noted on the listing.

To match Radar and ADAS data at the exact same times, a linear interpolation is made of the ADAS data.

Data from the different sources will not occur at the same sample rate. Because a uniform rate is required for statistical analysis, a least squares fit is made of the data and values from all sources are established at the same sample rate.

The initial flight's data are placed on the New Flight File. If not the initial flight, the data are added to previous data and are placed on the New History Flight File (Old History Flight File on next flight). While a time history plot and listing of the data are available, it is recommended that at least three flights be obtained before a statistical analysis is made.

THEORY

The methods to calculate the 50th and 90th percentile and confidence limits on the 50th percentile used in the analysis program are presented in this section. Two methods are incorporated in the program for calculating the 50th percentile value.

The following definitions are used throughout this section:

x = latitude error (nm)

y = longitude error (nm)

r = radial error ($\sqrt{x^2 + y^2}$) (nm)

m = number of tests

i subscript = test, i = 1 thru m

q = a variable

Σq_i = sum of a q_i for i = 1 thru m

μ_q = mean or expected value of q

$\sigma^2{}_q$ = variance of q

$\bar{q}$ = sample mean of q = $\Sigma q_i/m$

$S^2{}_q$ = sample variance of q = $\{\Sigma(q_i - \bar{q})^2\}/m$

The first method used to calculate percentiles of radial error (R50 and R90) is based on the Air Standard 53/11.B, 15 August 1968, The Specification and Evaluation of the Accuracy of Inertial Navigation System. The computations for R50 and R90 are made at each time point in the following manner:

Suppose, at some point in time, there are m radial errors (r_i, 1, m) from the m corresponding flights in the sample.

1. Calculate the geometric mean[1] (GM) of the radial errors:

   $GM = \sqrt[m]{\Pi r_i}$ where: Π = the product

2. Calculate the root mean square[1] (RMS) of the radial errors:

   $RMS = \sqrt{\Sigma r^2{}_i/m}$

3. Calculate the ratio = GM/RMS

4. Define RATIO = GM/RMS and calculate the R50 and R90 values from:

$$\left.\begin{array}{l} R50 \simeq RMS\ (.7\ RATIO + .3) \\ R90 \simeq RMS\ (1 + \sqrt{1 - RATIO}) \end{array}\right\} \quad \text{for RATIO} < .6$$

$$\left.\begin{array}{l} R50 \simeq RMS\ (.7\ RATIO + .4\ \sqrt{RATIO}) \\ R90 \simeq RMS\ \{RATIO + 1.6\ (1 - RATIO^2)\} \end{array}\right\} \quad \text{for RATIO} \geq .6$$

The second method used to calculate the percentile of radial error (CEP only in this program) is based on a paper by L. L. Rosen and D. L. Harmer titled "Inertial System Performance Evaluation" which was presented at the Third Inertial Guidance Test Symposium at Holloman AFB, New Mexico, in 1966. A procedure for calculating confidence limits on this CEP is also given in this paper.

At each time point the percentiles of radial error are calculated from:

$$R_p = \sigma_y \sqrt{a\ (z'_p \sigma_z + \mu_z)^3}$$

where:

R_p = the pth percentile of radial error and z'_p = the pth percentile point of a zero mean normal distribution.

σ_y, a, σ_z, μ_z are calculated from the following set of formulas:

$\sigma_x \simeq S_x\sqrt{m/(m-1)}$; $\sigma_y \simeq S_y\sqrt{m/(m-1)}$

$\mu_x \simeq \bar{x}$; $\mu_y \simeq \bar{y}$

[1] Defined in glossary

$$K = \sigma_x/\sigma_y \; ; \quad d = \sqrt{\mu_x^2 + \mu_y^2}$$

$$n = K^2(2 - K^2) + 1 + (2/\sigma_y^2)(d^2 - \mu_x^2K^2 - \mu_y^2)$$

$$\lambda = K^2(K^2 - 1) + (1/\sigma_y^2)(2\mu_x^2K^2 + 2\mu_y^2 - d^2)$$

$$a = n + \lambda \; ; \quad b = \lambda/a$$

$$\mu_z = 1 - (2/9)(1 + b)/a - (40/81)(b^2/a^2)$$

$$\sigma_z = \sqrt{(2/9)(1 + b)/a + (16/27)(b^2/a^2)}$$

The 50th percentile (CEP) is calculated from:

$$R_p = CEP \approx \sigma_y\sqrt{a\mu^3{}_z}$$

since:

$$z_p' = o \text{ for } p = 50$$

At each time point the 100 (1 - α)$^{\%}$ percent confidence limits on CEP ($L_1 < CEP < L_2$) are approximated by substituting the upper and lower confidence limits of the means and sigmas calculated below into the formulas above:

The confidence limits on the means are calculated using a "t test":[1]

$$|\bar{x}| - \{(t_\alpha/2)(\sigma_x/\sqrt{m})\} < \mu_x < |\bar{x}| + \{(t_\alpha/2)(\sigma_x/\sqrt{m})\}$$

$$|\bar{y}| - \{(t_\alpha/2)(\sigma_y/\sqrt{m})\} < \mu_y < |\bar{x}| + \{(t_\alpha/2)(\sigma_y/\sqrt{m})\}$$

The confidence limits on the sigmas are calculated using a "chi test".[1]

$$\{S_x\sqrt{m/(m - 1)}\}/(\chi_1 - \alpha/2) < \sigma_x < \{S_x\sqrt{m/(m - 1)}\}/\chi_\alpha/2$$

$$\{S_y\sqrt{m/(m - 1)}\}/(\chi_1 - \alpha/2) < \sigma_y < \{S_y\sqrt{m/(m - 1)}\}/\chi_\alpha/2$$

where:

$t_\alpha/2$ is the upper 100 (α/2) percent point of the "t distribution" with m - 1 degrees of freedom. $\chi_\alpha/2$ and $\chi_1 - \alpha/2$ are the lower and the upper 100 (α/2) percent points of the "chi distribution" with m - 1 degrees of freedom.

The lower limit of the CEP (L_1) is calculated by using the lower limits of mean and sigma to calculate $L_1 = \sigma_y\sqrt{a\mu_z^3}$. Should the lower limits of the means be negative, a zero is substituted for this lower limit in the computations of L_1.

The upper limit of the CEP (L_2) is calculated by using the upper limits of mean and sigma to calculate $L_2 = \sigma_y\sqrt{a\mu_z^3}$.

PREPARATION FOR USE

The program deck of NAVAN will be permanently stored on magnetic tape number 04295 at the AFFTC tape library. Prior to a first use, the compiled file must be copied to disc and stored as a permanent file as

[1] Defined in glossary

shown in figure A1. Once the program is stored as a permanent file, it may be attached and executed.

SCOPE OF PROGRAM

This program uses control information from data cards and extracts selected test data information from one or certain combinations of the following inputs: (1) An Automatic Data Acquisition System (ADAS) tape (produced at the AFFTC), (2) A radar tape (produced at the AFFTC), (3) Card data containing navigation system time, latitude, and longitude, and (4) Card system data containing time, latitude, and longitude position error. The program then merges the data, edits wild points, performs various calculations, produces plots on the Calcomp plotter, and produces printed output of the computations.

Generalized flowcharts of the three data sources (ADAS - radar, radar card, and system card) are shown in figures A2, A4, and A6 respectively. Detailed flowcharts are shown in figure A29. The subroutines, ADADATA, RADRD, and CRDDATA, select the times and parameters from the data sources. Multiple events on the ADAS tape are read with one start and stop time. A wild point check is made on the radar data only, based on a maximum aircraft horizontal velocity of 900 feet per second. (Values replaced are noted on output listing.) This value may be changed by the user if required. Any radar data input at the time that the velocity exceeds 900 feet per second is replaced with the last inbound value. The radar data is then merged with the ADAS or system card data, based on the time of the radar data point. A linear interpolation is used to obtain the data value at the time of the radar data point. The radar latitude and longitude is subtracted from the system latitude and longitude. The resulting error is converted to nautical miles and the radial error is computed for each data point. A least squares curve fit is then made of the data in order to obtain a constant sample rate. The sample rate output is a user defined option.

Note: For valid statistical data, the sample rate should be the same for all flights, regardless of the data source (ADAS - radar, radar card, or system card). This data is now placed on the New Flight File (tape 16). Tape 16 may be optionally printed or plotted. Tape 16 is normally the input to NAVMR. This is combined with the file containing data from the other flights to be analyzed (tape 17). This merged data is placed on the New History Flight File (tape 11), and may also be optionally printed. Tape 11 is the input to NAVAN which performs the statistical calculations of the data to be analyzed. An important user defined variable in NAVAN is the time span over which each calculation occurs. This time span should be equal to the time between samples. This is done to obtain only one data value per flight number per time span, in order to maintain statistical validity for the calculated confidence intervals. NAVAN generates both Calcomp plots of the data and a computer listing.

USER'S GUIDE

Listed below are the necessary tapes for options being used:

LIST OF FILES

FILE NO.	DESCRIPTION
4	Search File (Internal Operating File)
5	Input (Card Input)
6	Output (Printer Output)
7	Input (ADAS Tape)
8	Input (Radar Tape)
9	I/O (ADAS Selected Parameters)
10	Output (Optional, from NAVAN for Debugging)
11	New History Flight File (NHF, New Data Base)
12	I/O (Statistical Data for Plot, Internal Working File)
13	Calcomp Plot Tape
16	I/O (New Flight File, NFF)
17	Input (Old History File, OHF, Old Data Base)
22	I/O (Radar Selected Parameters)
23	Internal Working File

The output data from NAVAN consists of an output file computer listing, as in figure A8, and Calcomp plots, as in figures A9, A10, and A11. The New History Flight File (file 11) contains all of the previously processed flights sequentially arranged in order of increasing time. The output listing contains a copy of all of the input cards and a copy of all of the processed data. This can be used to check the validity of the data prior to plotting.

INPUT CARDS FOR NAVAN

The cards for the three different input options are described separately.

ADAS - RADAR COMBINATION DATA

NAVAN data card #1, figure A12, is used to pick the input option, INOP(2)=1, for ADAS and Radar tapes, set the slope of the CEP line to be drawn on the Calcomp plots and select other program options. The NAMELIST format is used to read in data. A card must start in column 2 with $DATA and be terminated with a $ sign. Three additional input options may be specified on this card. Normally 900 ft/sec is used internally for wild point checking, but this may be reset to another value by placing N900=XXXX.XX (the new value) on the card. (Care should be taken that the actual aircraft velocity does not exceed 900 ft/sec.)

NAVAN data card #2, figure A13, contains the number of parameters to be selected from the ADAS tape and the parameter ID codes. Note: One data word may be made-up of two words containing the most and least significant data bits.

NAVAN data card #3, figure A14, contains data to correct the time on the ADAS tape to the time on the radar tape. This card also contains the navigation system start time.

NAVAN data card #4, figure A15, contains the start and stop search times in total seconds.

NAVAN data card #5, figure A16, is in NAMELIST format and starts with a $NAM1 in column 2 and is terminated with a $ sign. The next entry is the start time, in seconds, on the New History Flight File, tape 11, where data calculations start. Next, the stop time, in seconds, on tape 11 is listed. The time span for calculations is specified and should be selected so as to have one data point per time span per flight for the best statistical validity (standard time 300 seconds).

NAVAN data cards #6, #6A, #7, #8, and #9, figures A17, A18, A19, and A20, are only required for Calcomp plots. Data card #6 has the X-axis and Y-axis scale factors for each plot, the initial value for the X-axis, the number of plots, and a plot heading code. The number of plots is equal to three times the number of runs. The plot heading code must be equal to 1 for a heading and 0 or blank for no heading. Data card #6A contains the heading. Data card #7 has the axes lengths for Calcomp plot #1, figure A9, and the starting value for the Y-axis. Data card #8 is the same as data card #7, but contains information for Calcomp plot #2, figure A10. Data card #9 is the same as data cards #7 and #8, but contains information for Calcomp plot #3, figure A11.

If there is to be more than one data run, cards with the new values should be repeated. The end of the data request should be indicated by a blank data card, figure A21.

SYSTEM CARD DATA

This is the case where system error data will be entered on cards.

NAVAN data card #1, figure A22, starts with a $DATA in column 2 and terminates with a $ sign. The NAMELIST format is used to read in data. This card should be coded with INOP(3)=1 and INOP(10)=1, to indicate that the data cards will have latitude and longitude in degrees. Other input options are the same as for ADAS - Radar Combination Data, figure A12.

NAVAN data card #2, figure A23, will be the first data card. One card will be read for each data point, and the final data value will be -100000.00, figure A24. The following cards after the final data value will be the same as for ADAS - Radar Combination Data.

RADAR CARD DATA

This is the case where radar tracking data are available and system data are on cards.

NAVAN data card #1, figure A25, starts with a $DATA in column 2 and terminates with a $ sign. The NAMELIST format is used to read in data. This card will contain the codes INOP(4)=1 and INOP(10)=1, with the other input options the same as for ADAS - Radar Combination Data, Figure A12.

NAVAN data card #2, figure A26, contains the start and stop times for the radar tape, and the navigation system start time.

NAVAN data card #3, figure A27, is the first data card and should be repeated for each data point, and the final data value will be -100000.00, figure A28. The following cards after the final data value will be the same as for ADAS - Radar Combination Data.

FIGURE A1 SAMPLE DECK SETUP TO COPY NAVAN TO PERMANENT FILE.

ADAS-RADAR COMBINATION DATA

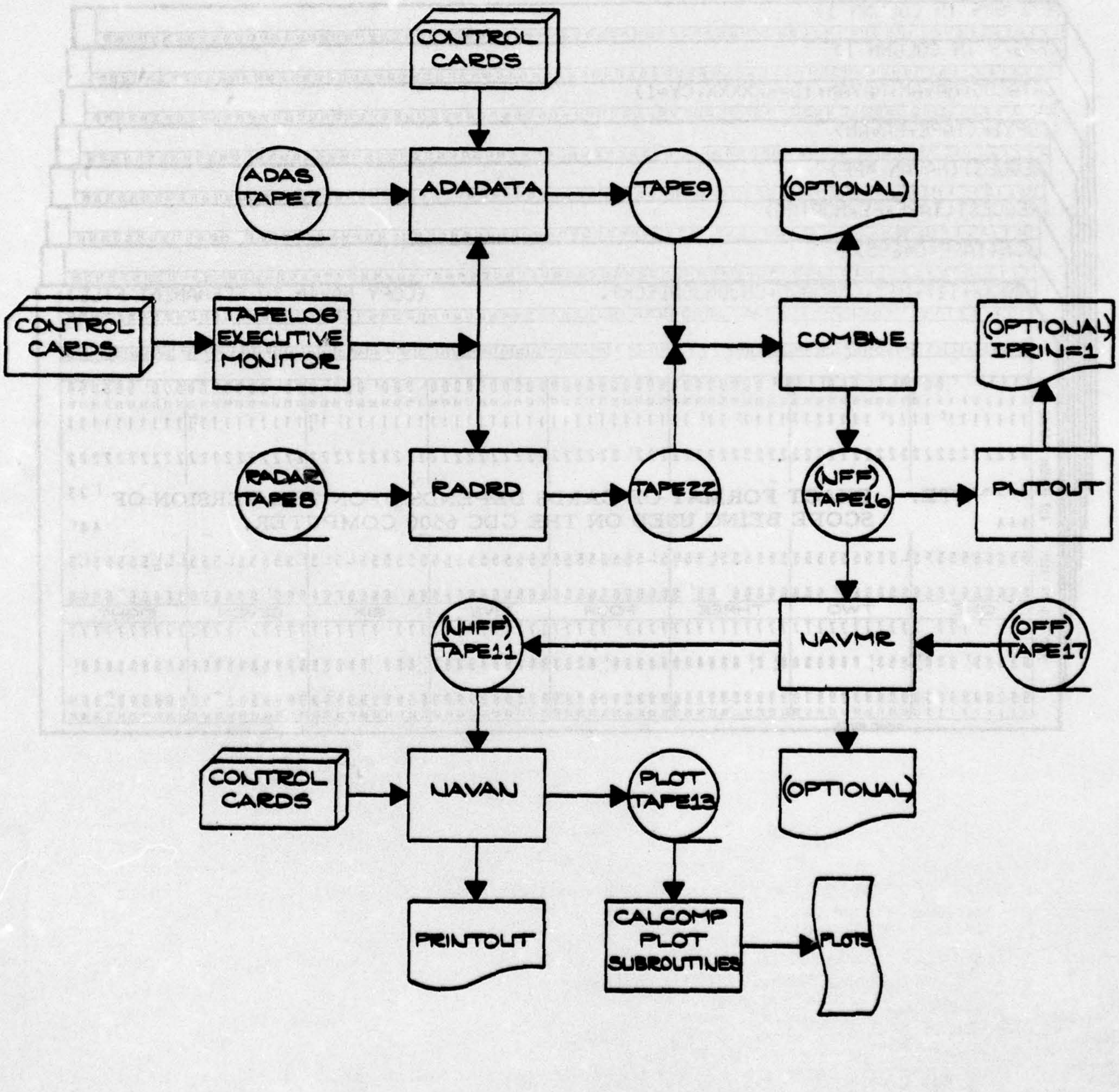


FIGURE A2 GENERALIZED FLOWCHART

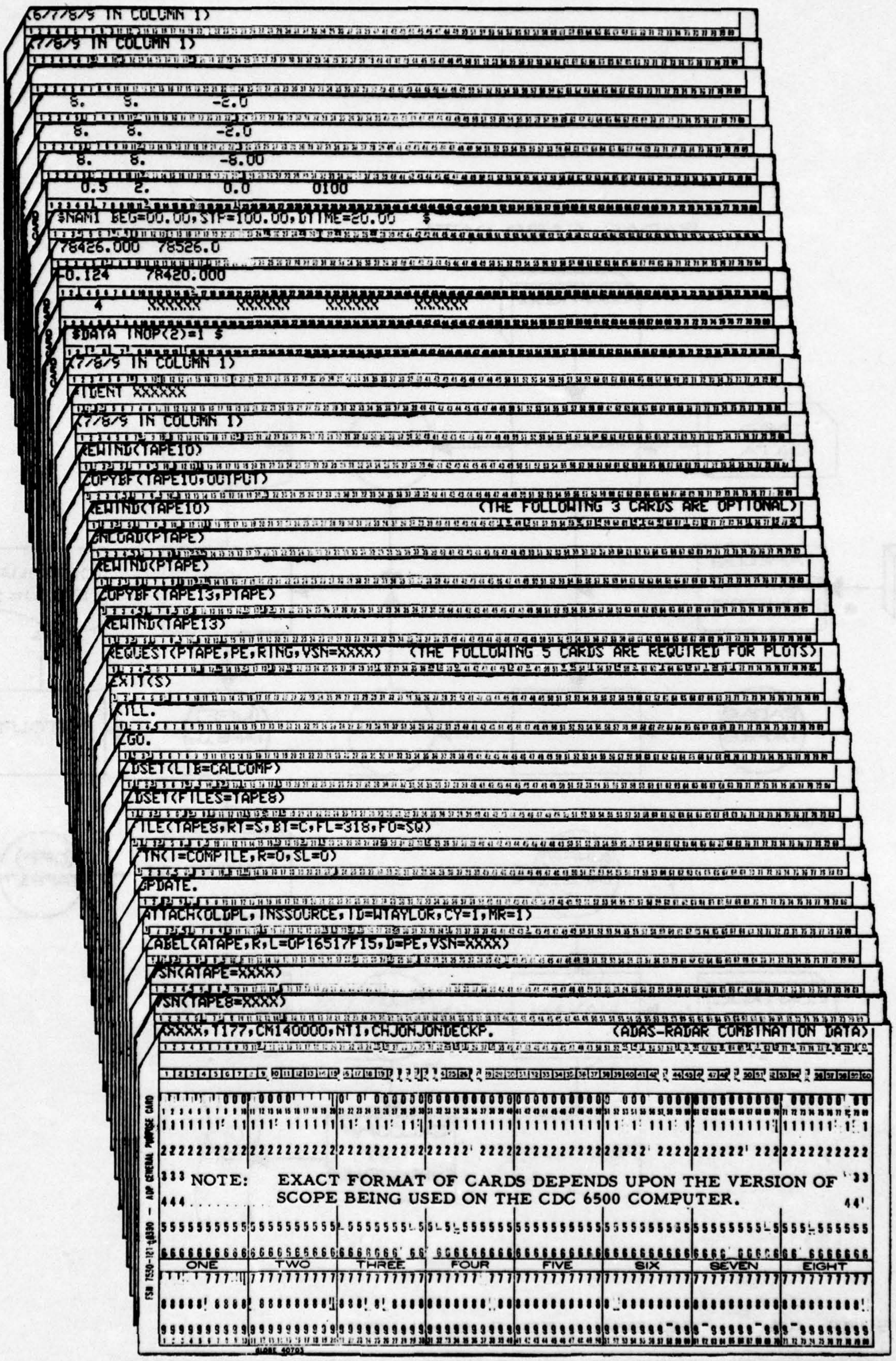


FIGURE A3 SAMPLE DECK SETUP TO RUN ADAS-RADAR COMBINATION DATA.

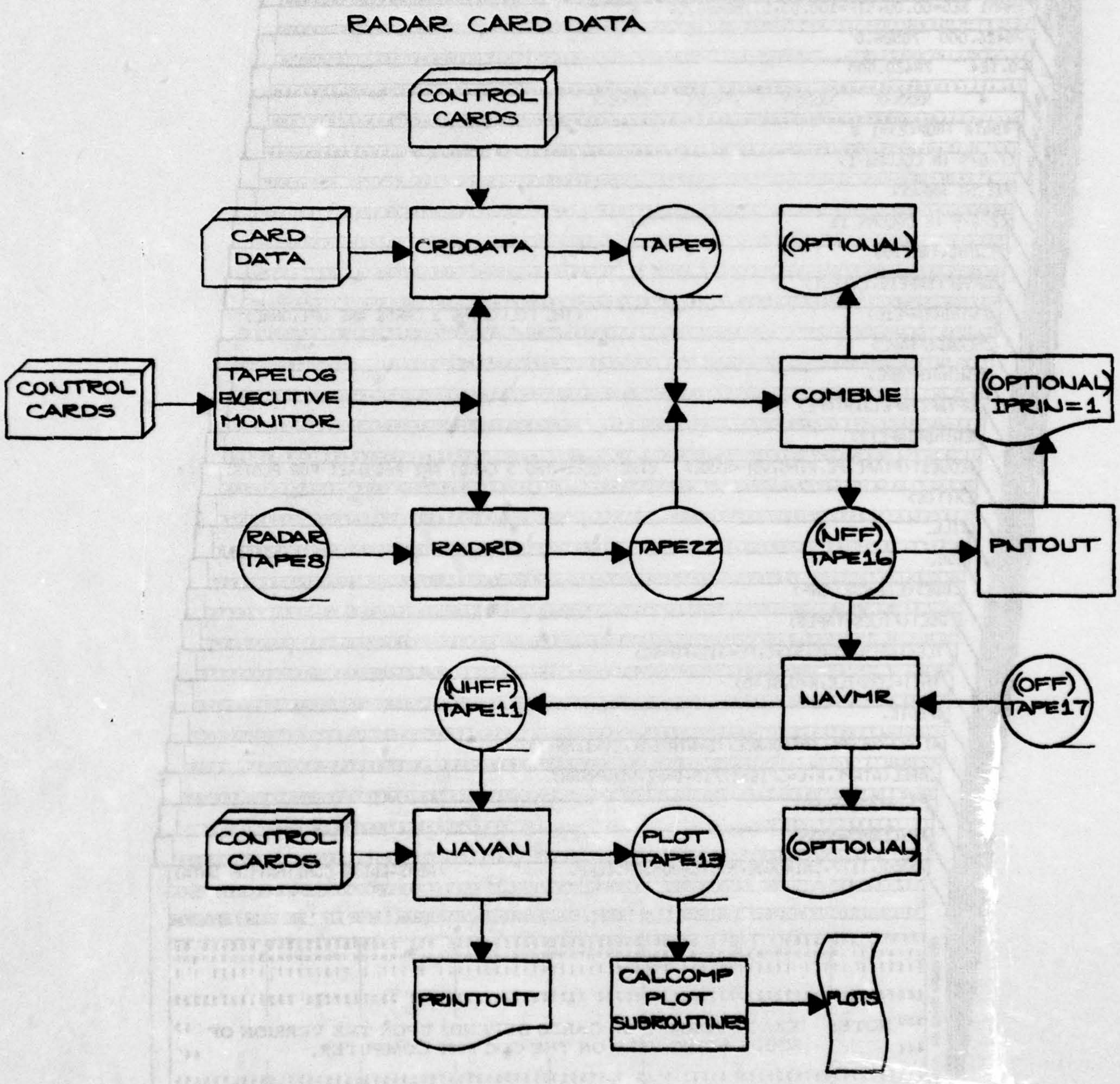


FIGURE A4 GENERALIZED FLOWCHART

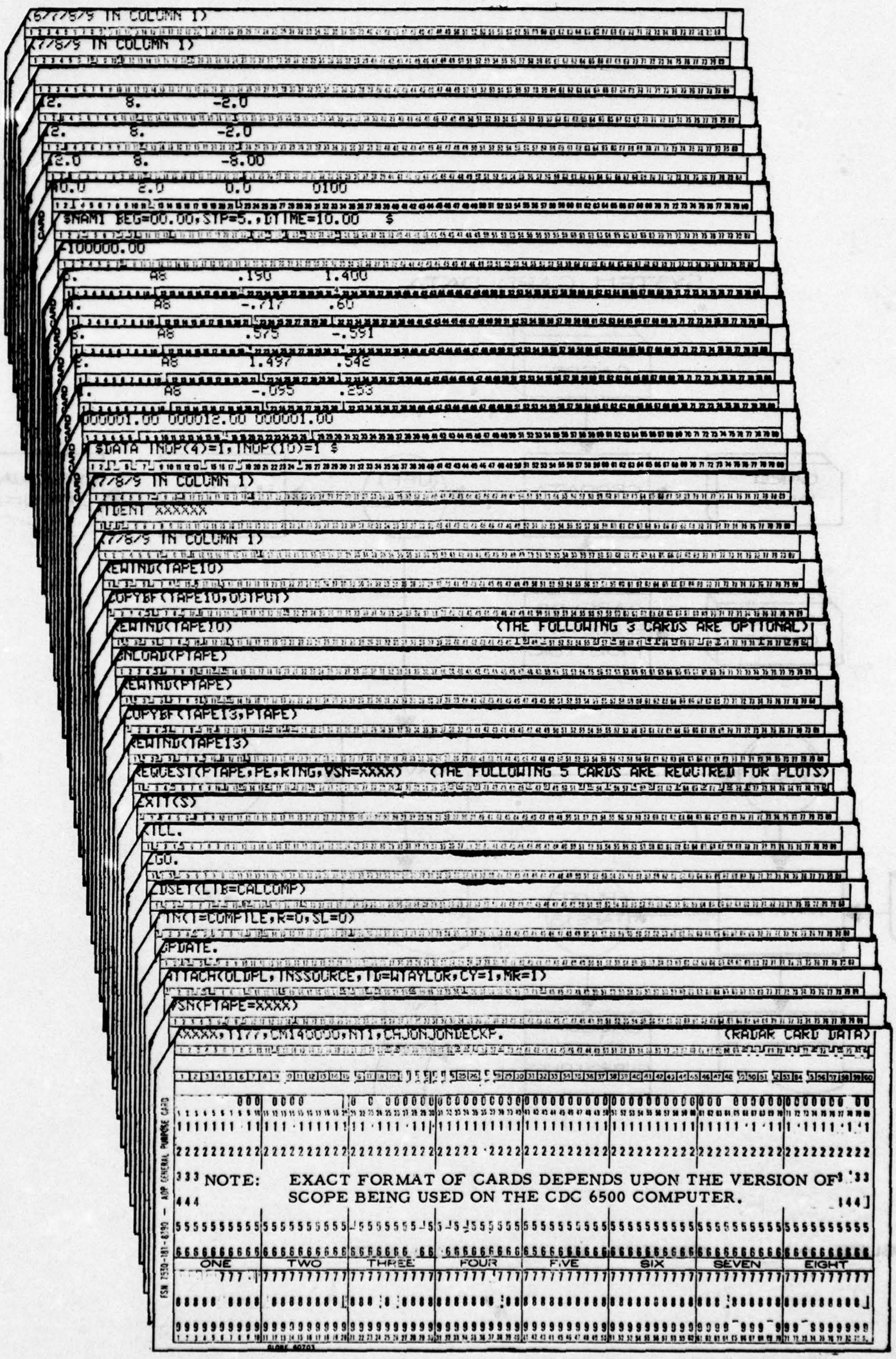


FIGURE A5 SAMPLE DECK SETUP TO RUN RADAR CARD DATA.

SYSTEM CARD DATA

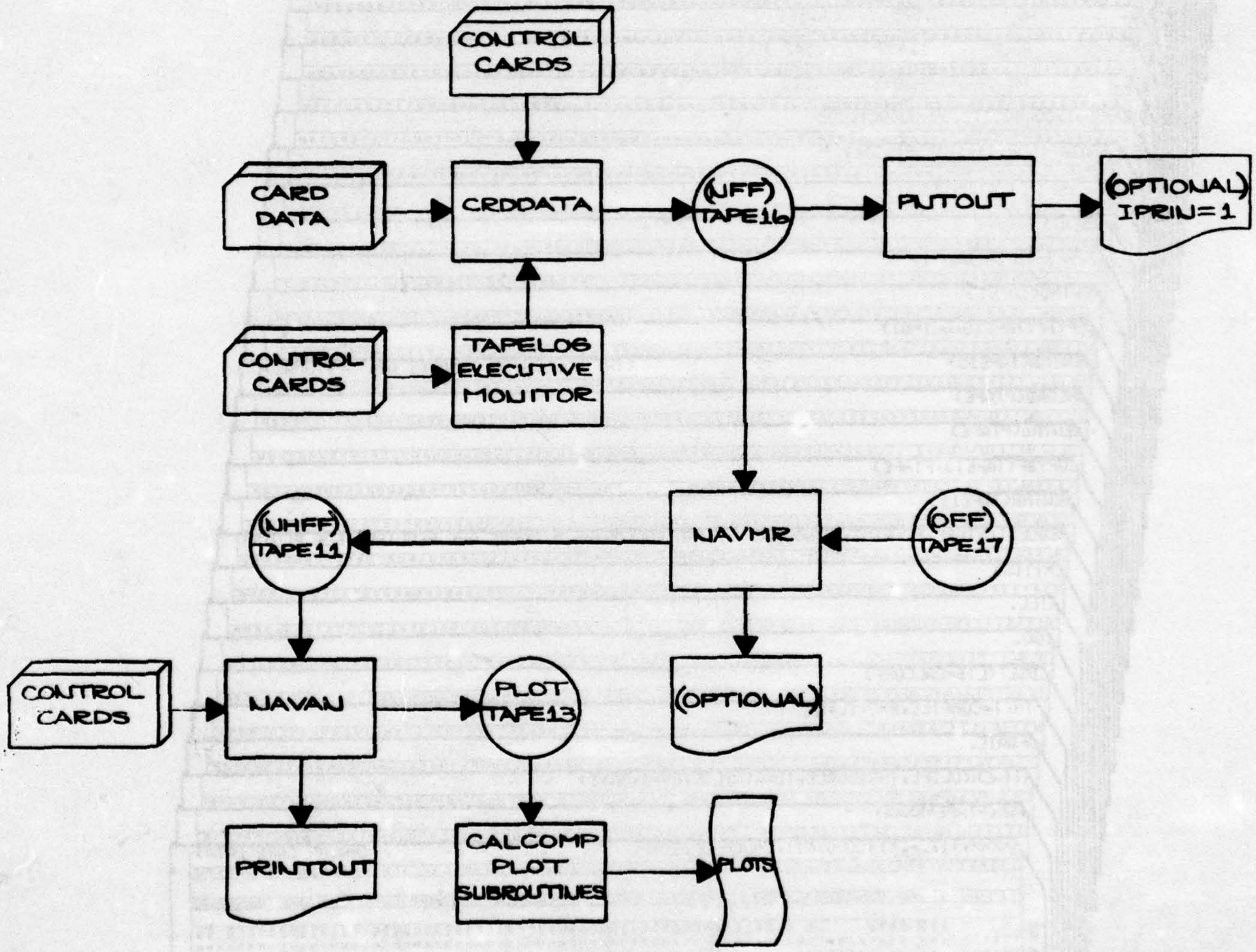


FIGURE A6 GENERALIZED FLOWCHART

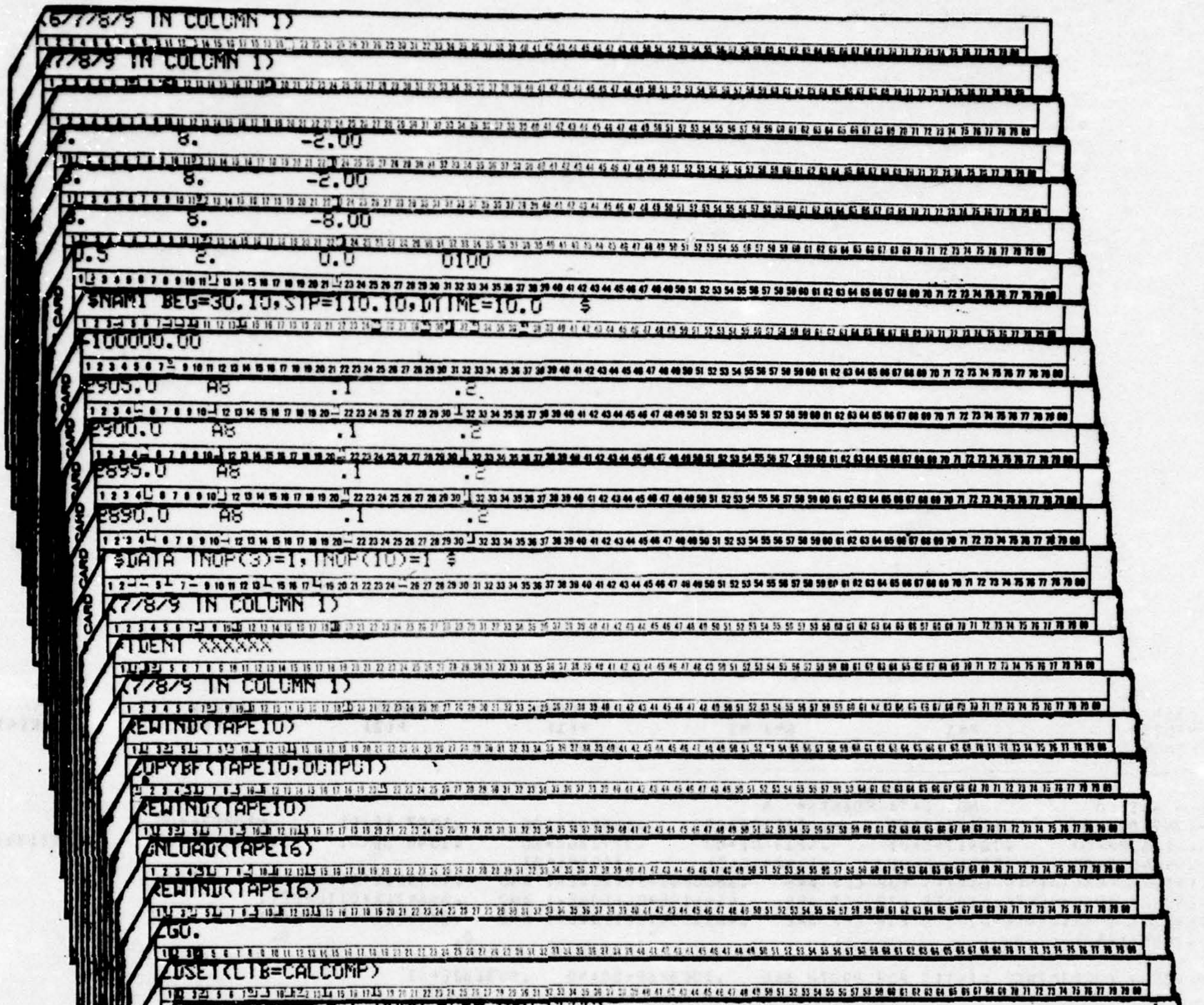


FIGURE A7 SAMPLE DECK SETUP TO RUN SYSTEM CARD DATA.

```
MEAN LAT        SIGMA LAT        MEAN LONG        SIGMA LONG        MEAN R        SIGMA R
MEDIAN R        RMS              GM/RMS           P(1)              P(2)          P(3)          P(4)
R50             R90              CEP              90THP

ME = 401.00              NO. DATA POINTS=  4
 -.762500E+00   .601511E+00   -.206250E+00   .668656E+00   .100711E+01   .625303E+00
  .916312E+00   .104175E+01    .921360E+00   .727286E+00   .104690E+01   .140312E+01   .175217E+01
  .984400E+00   .133388E+01    .104244E+01   .176068E+01
PERCENT CONFIDENCE LIMITS FOR CEP ARE   .386083E+00(LOWER) AND   .453326E+01(UPPER)
PERCENT CONFIDENCE LIMITS FOR CEP ARE   .414610E+00(LOWER) AND   .356431E+01(UPPER)
PERCENT CONFIDENCE LIMITS FOR CEP ARE   .465165E+00(LOWER) AND   .270121E+01(UPPER)
 .108661E+01    0.     0.     0.     0.     0.     0.

PERCENT CONFIDENCE LIMITS FOR P90TH ARE   .700326E+00AND   .803132E+01

  =      4
  =      .400000E+01
M1=      .300000E+01
LT=     -.762500E+00
LG=     -.206250E+00
R =      .100711E+01
S =      .104175E+01
LA=      .108545E+01
LG=      .134130E+01
R =      .117301E+01
LA=      .601511E+00
LG=      .668656E+00
R =      .625303E+00
P =      .104244E+01
ED =     .916312E+00
```

Figure A8   Program NAVAN Computer Output Listing

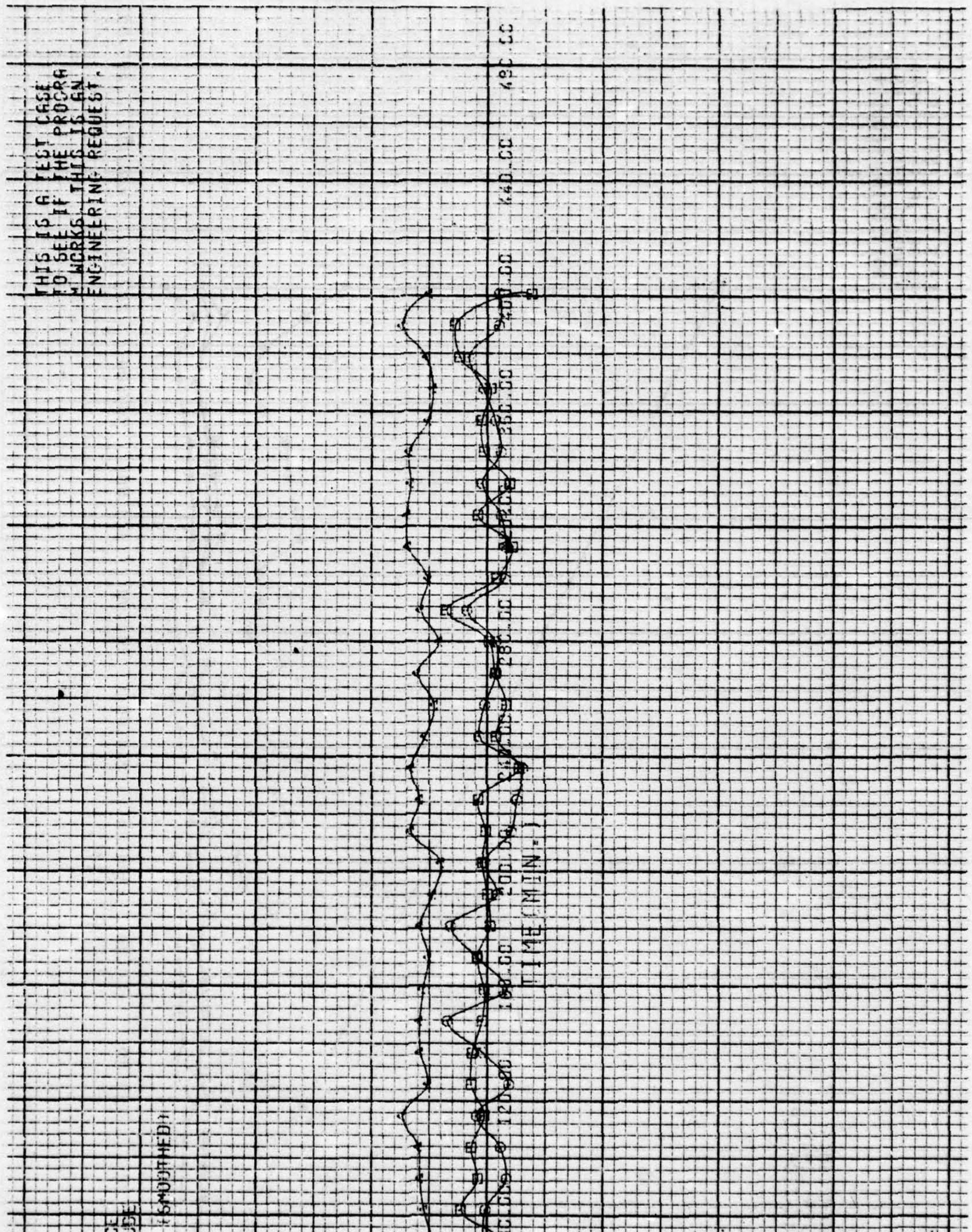


Figure A9. Program NAVAN Calcomp Output Plot No. 1

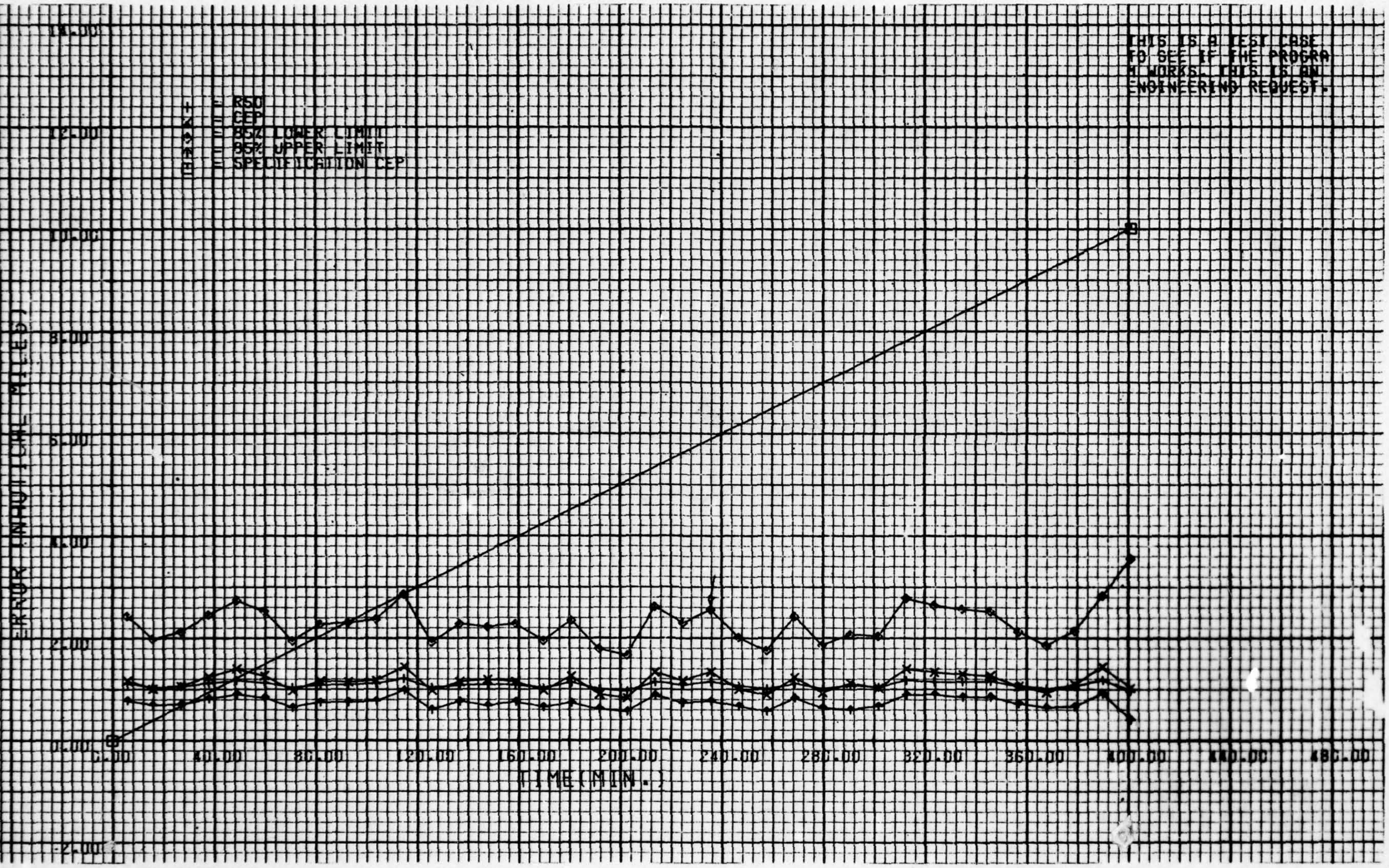


Figure A10 Program NAVAN Calcomp Output Plot No. 2

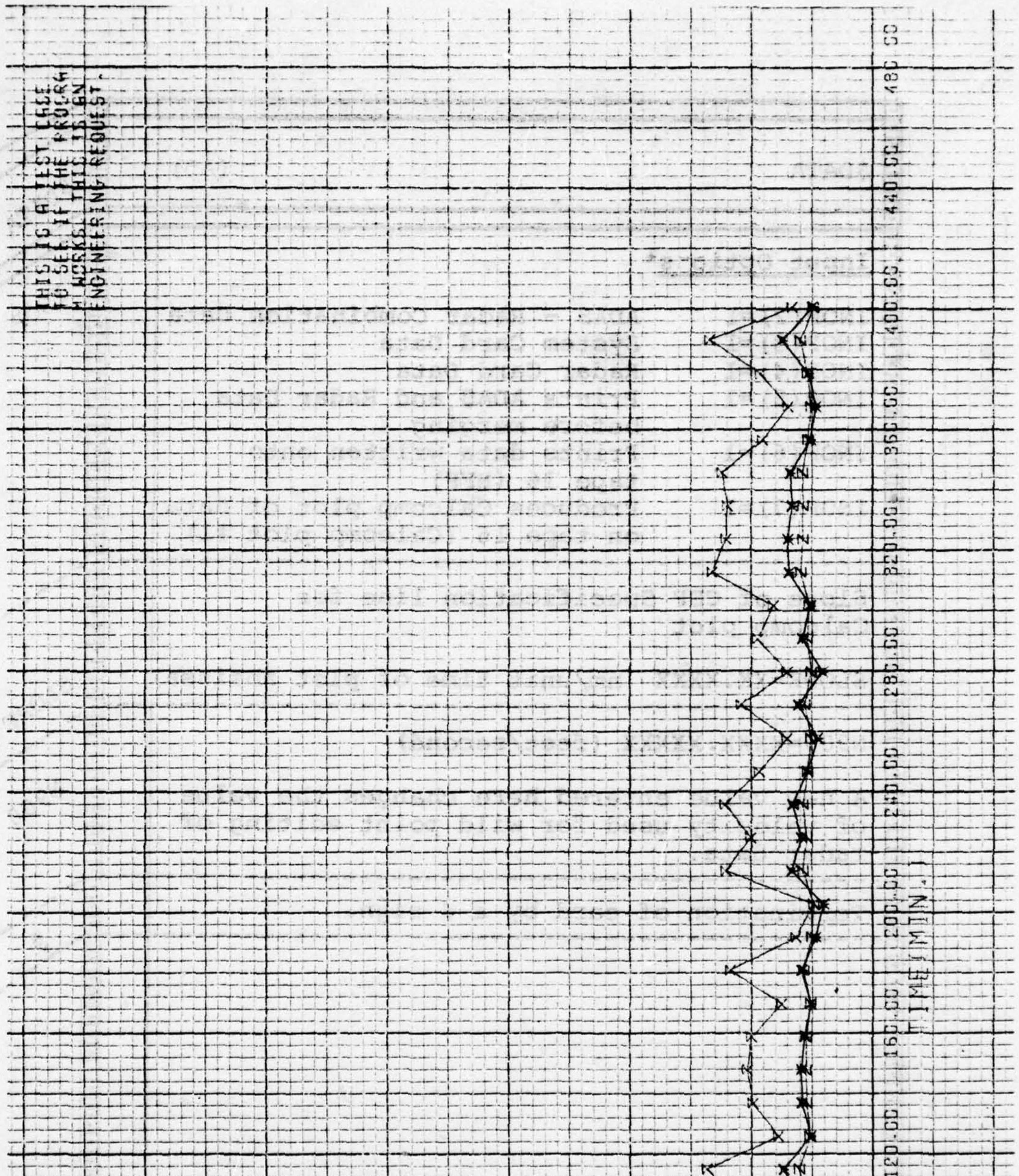


Figure A11 Program NAVAN Calcomp Output Plot No. 3

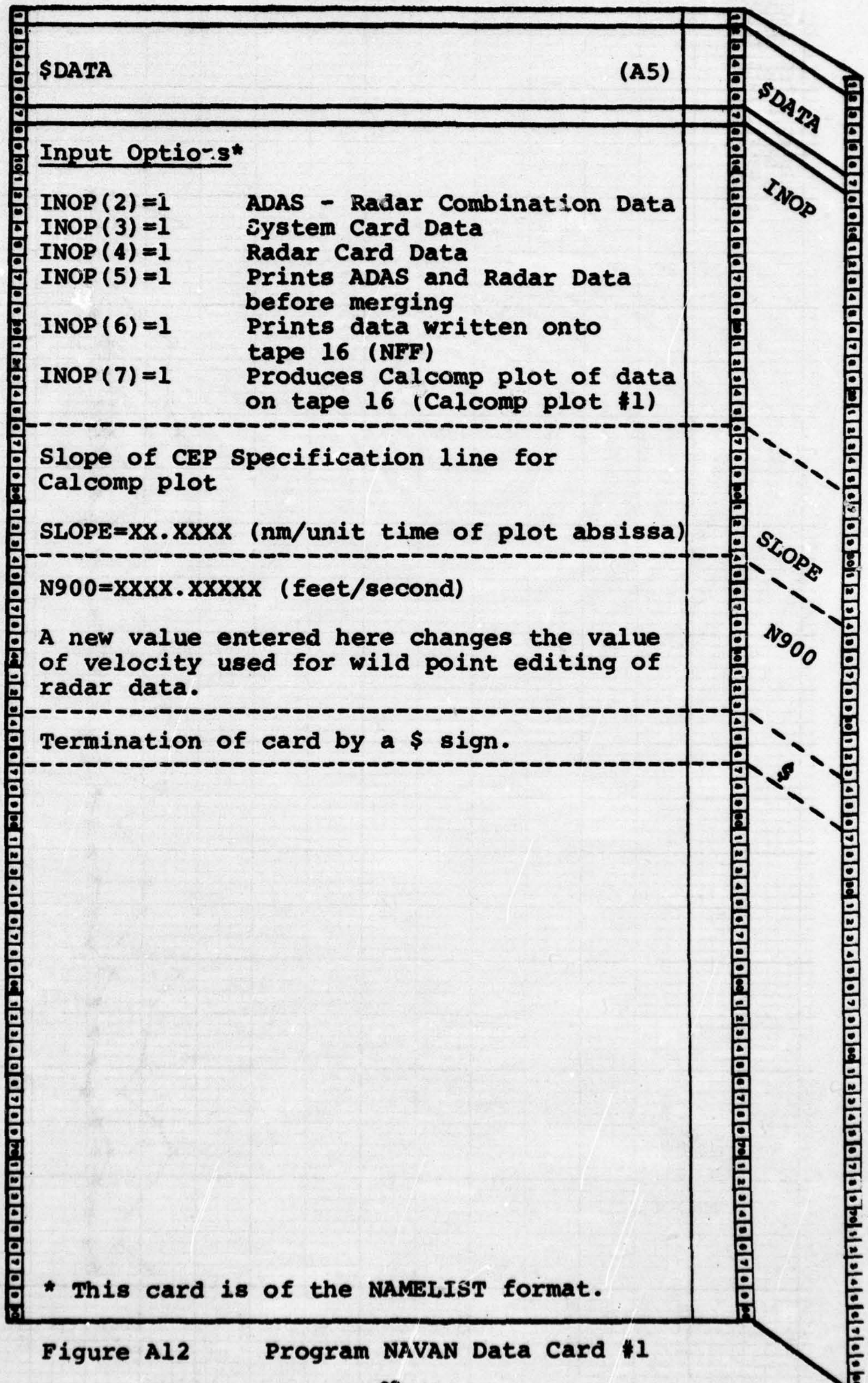


Figure A12 Program NAVAN Data Card #1

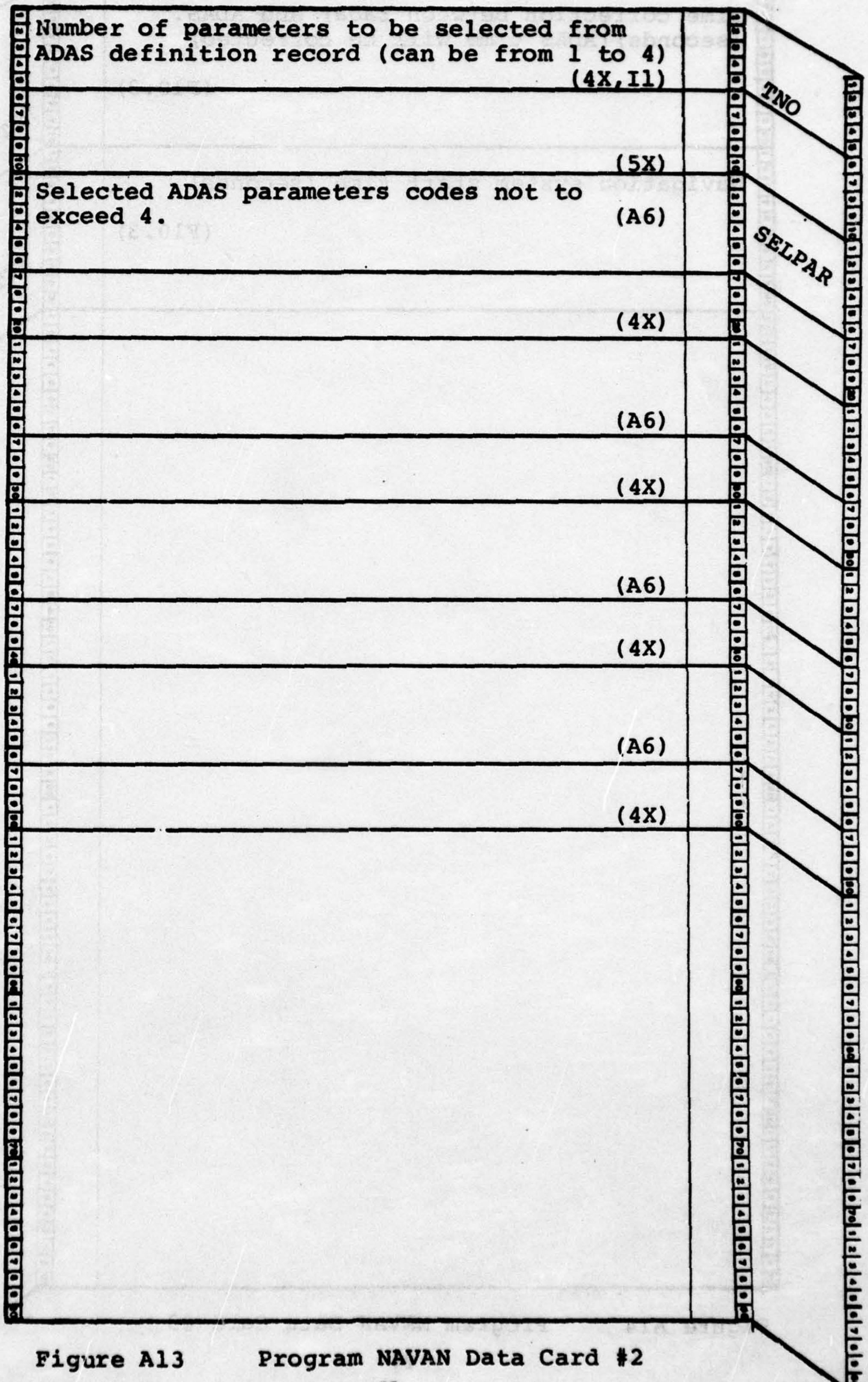


Figure A13 Program NAVAN Data Card #2

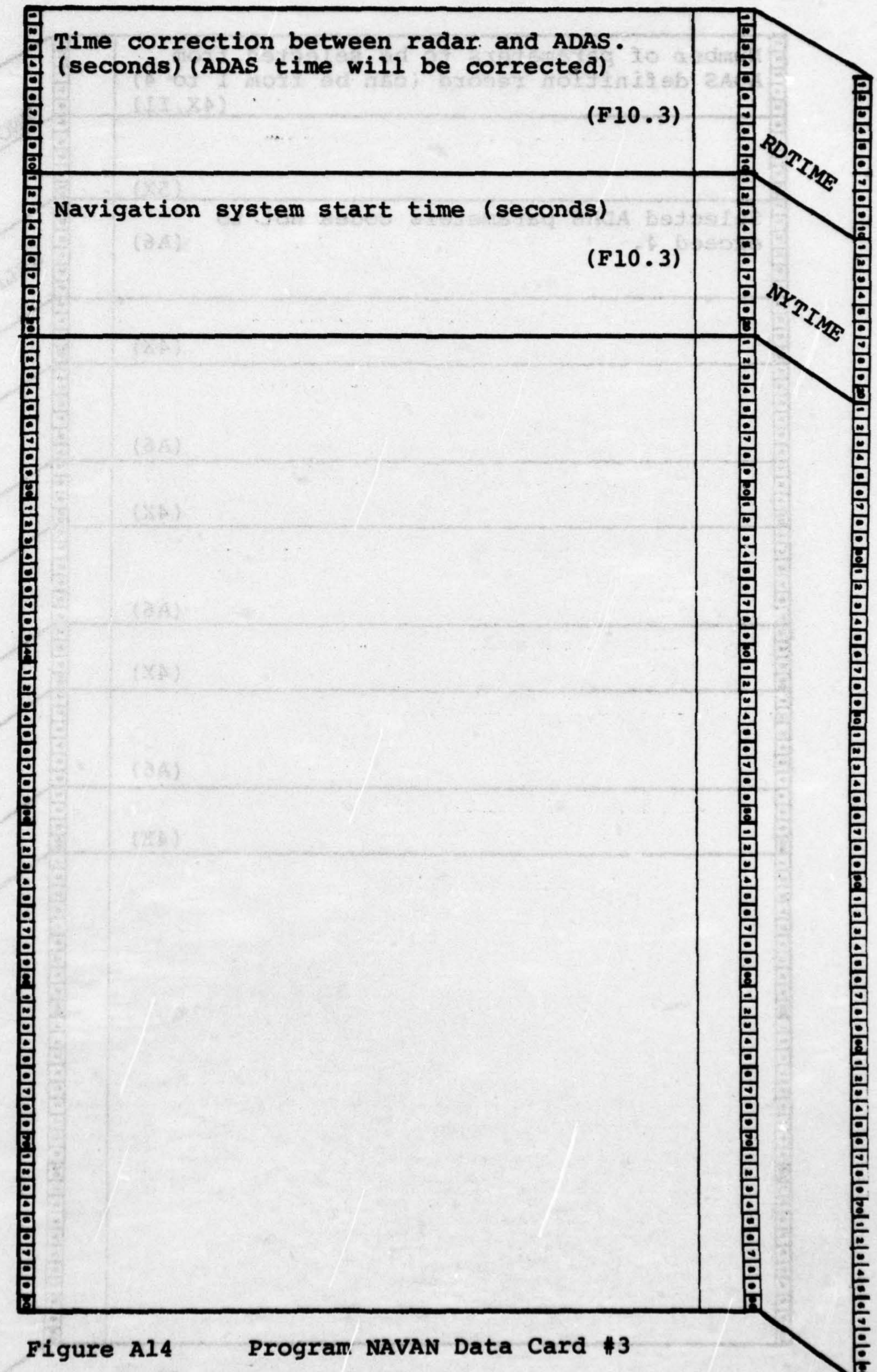


Figure A14 Program NAVAN Data Card #3

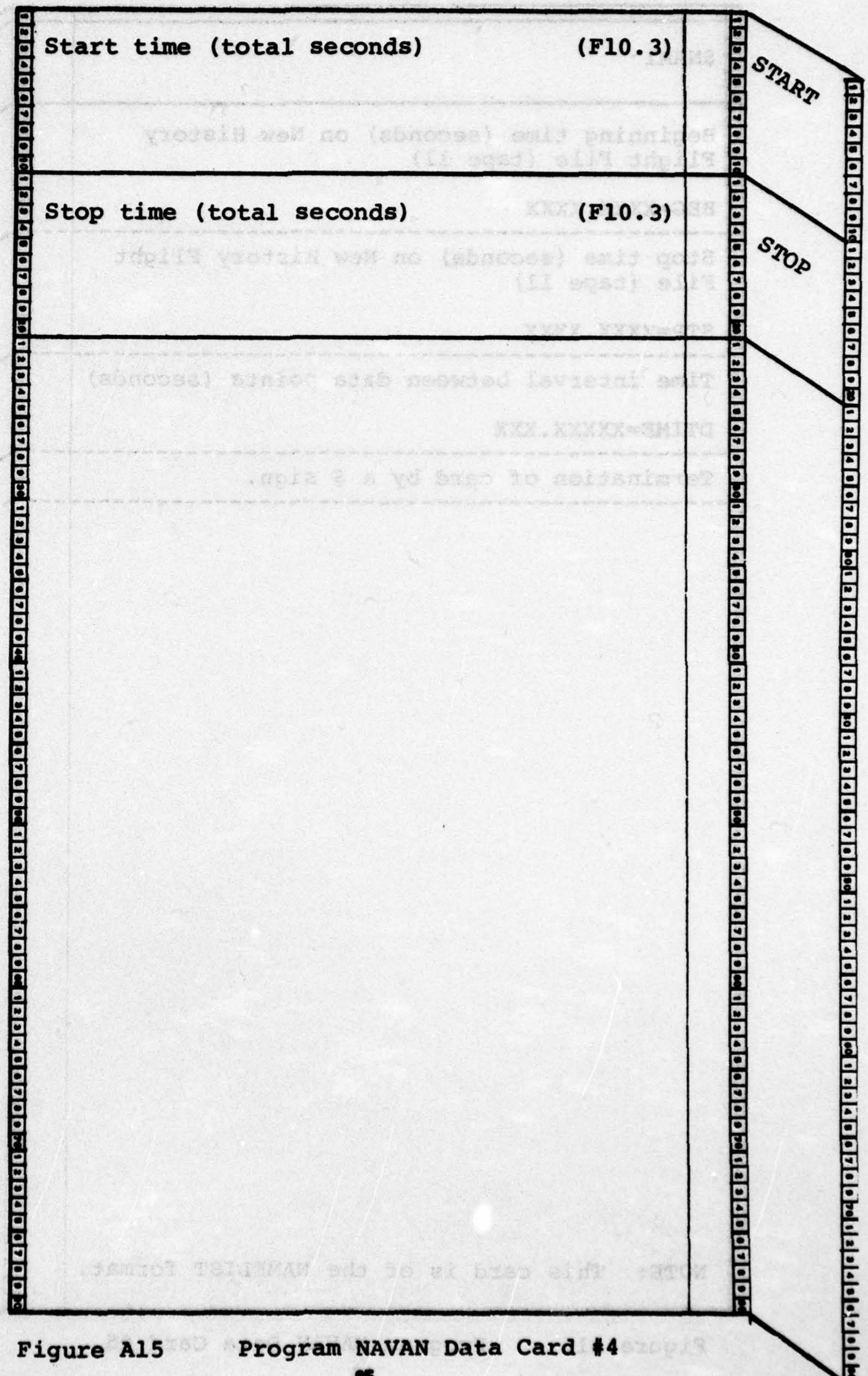


Figure A15 Program NAVAN Data Card #4

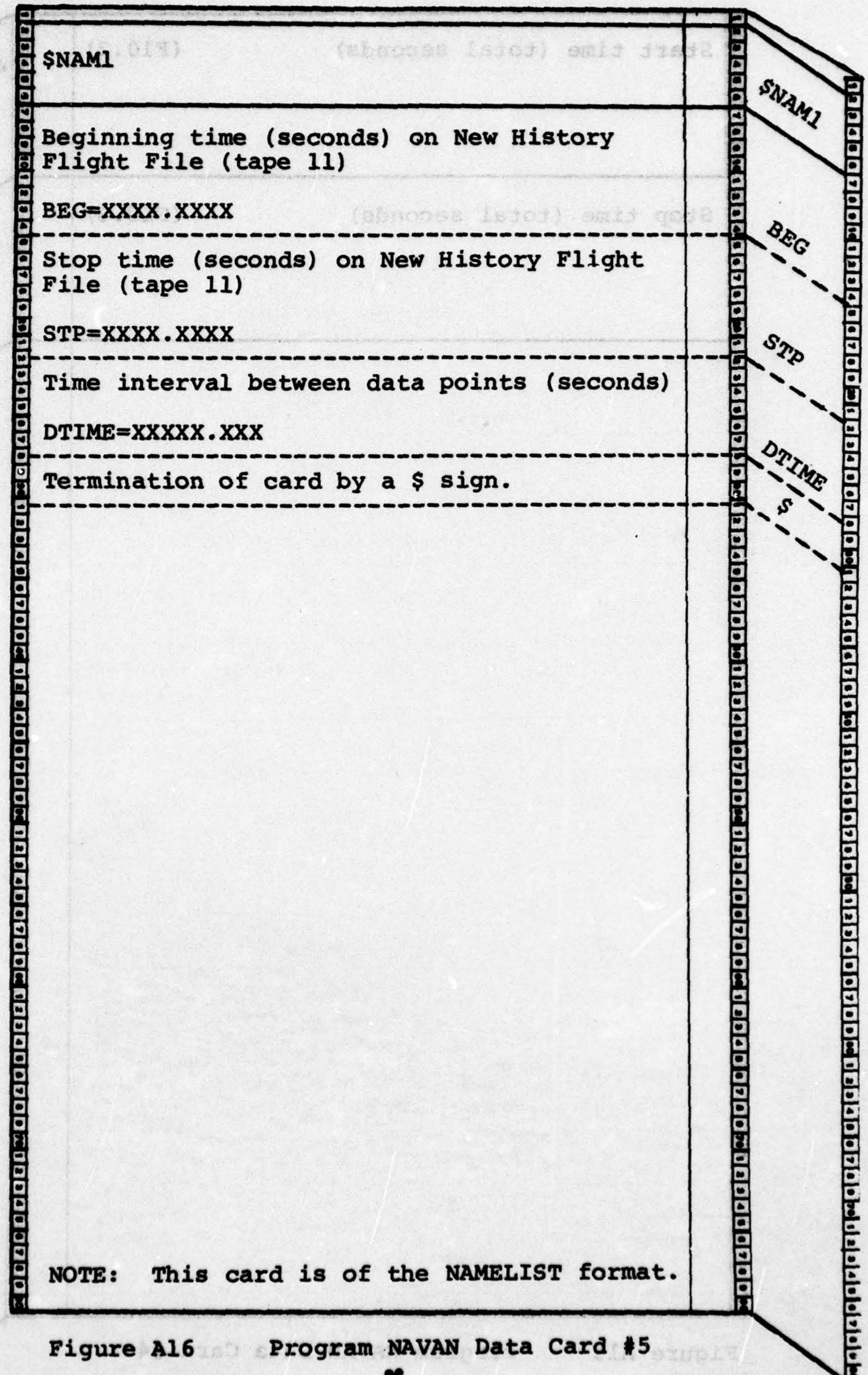


Figure A16 Program NAVAN Data Card #5

Scale for X-axis, (time), for all plots

minutes/inch (F10.3)

XINT

Scale for Y-axis, (nm), for all plots

nm/inch (F10.3)

YINT

Initial value for X-axis (minutes) (F10.3)

XST

No. of plots = 3 times no. of runs (I2)

NUM

Plot Heading * and ** (I2)

PHDG

Plot Heading Card ***

Starting in column 1 of a new card, the plot heading will be written as 4 lines of 20 characters each on all plots.

(8A10)

IWORD

* PHDG = zero or blank for no heading.

** PHDG = 1 for a heading.

*** Plot heading card not needed if PHDG<1.

Figure A17 Program NAVAN Data Card #6 and #6A

X-axis length (inches) for plot no. 1

(latitude error, longitude error, and radial error) (F10.3)

XLEN

Y-axis length (inches) for plot no. 1 (F10.3)

YLEN

Starting value of Y-axis for plot no. 1 (F10.3)

YST

COMMENT: Starting value for X-axis is the same for all 3 plots.

Figure A18 Program NAVAN Data Card #7

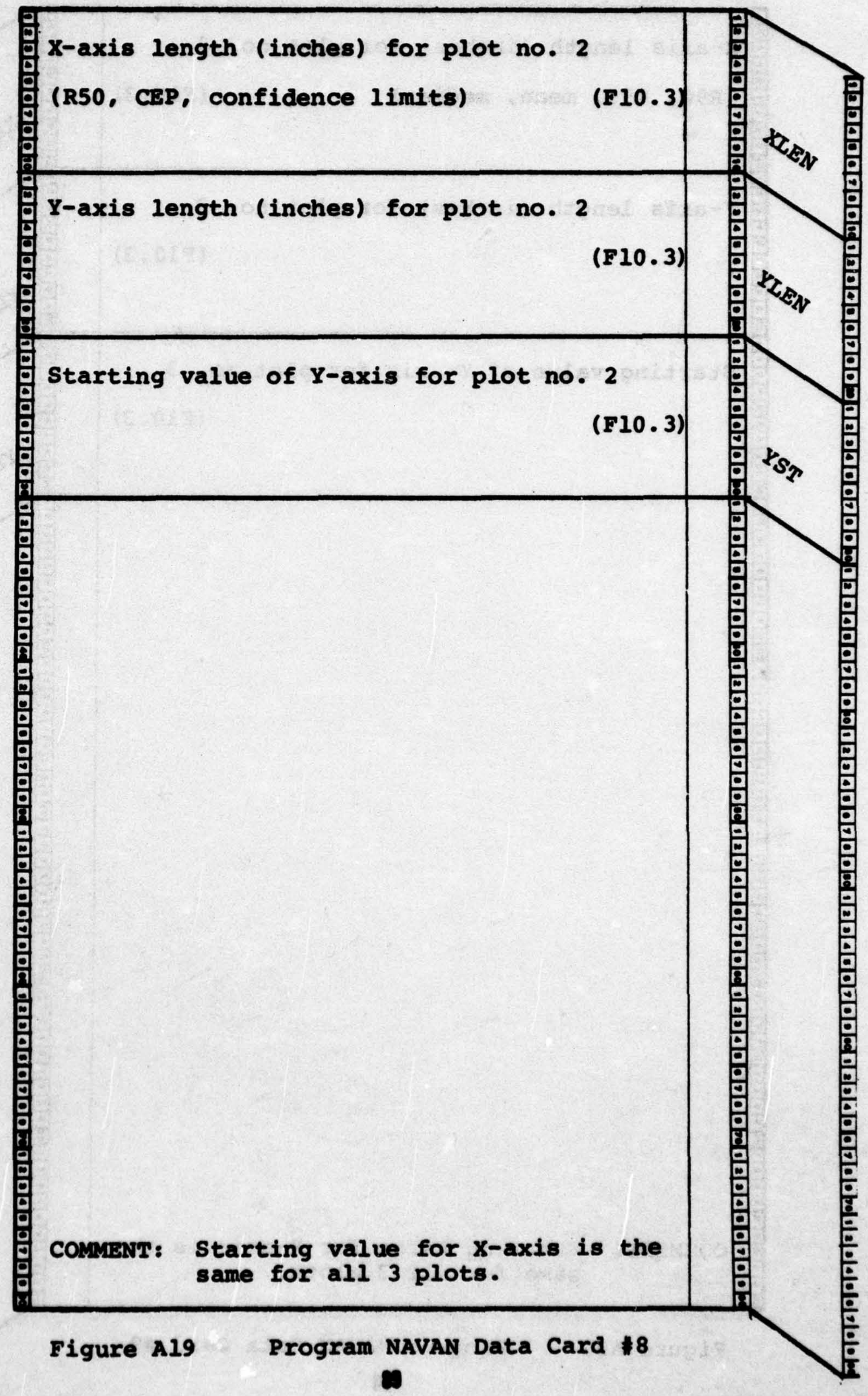


Figure A19 Program NAVAN Data Card #8

X-axis length (inches) for plot no. 3

(R90, R50, mean, median) (F10.3)

XLEN

Y-axis length (inches) for plot no. 3

(F10.3)

YLEN

Starting value of Y-axis for plot no. 3

(F10.3)

YST

COMMENT: Starting value for X-axis is the same for all 3 plots.

Figure A20 Program NAVAN Data Card #9

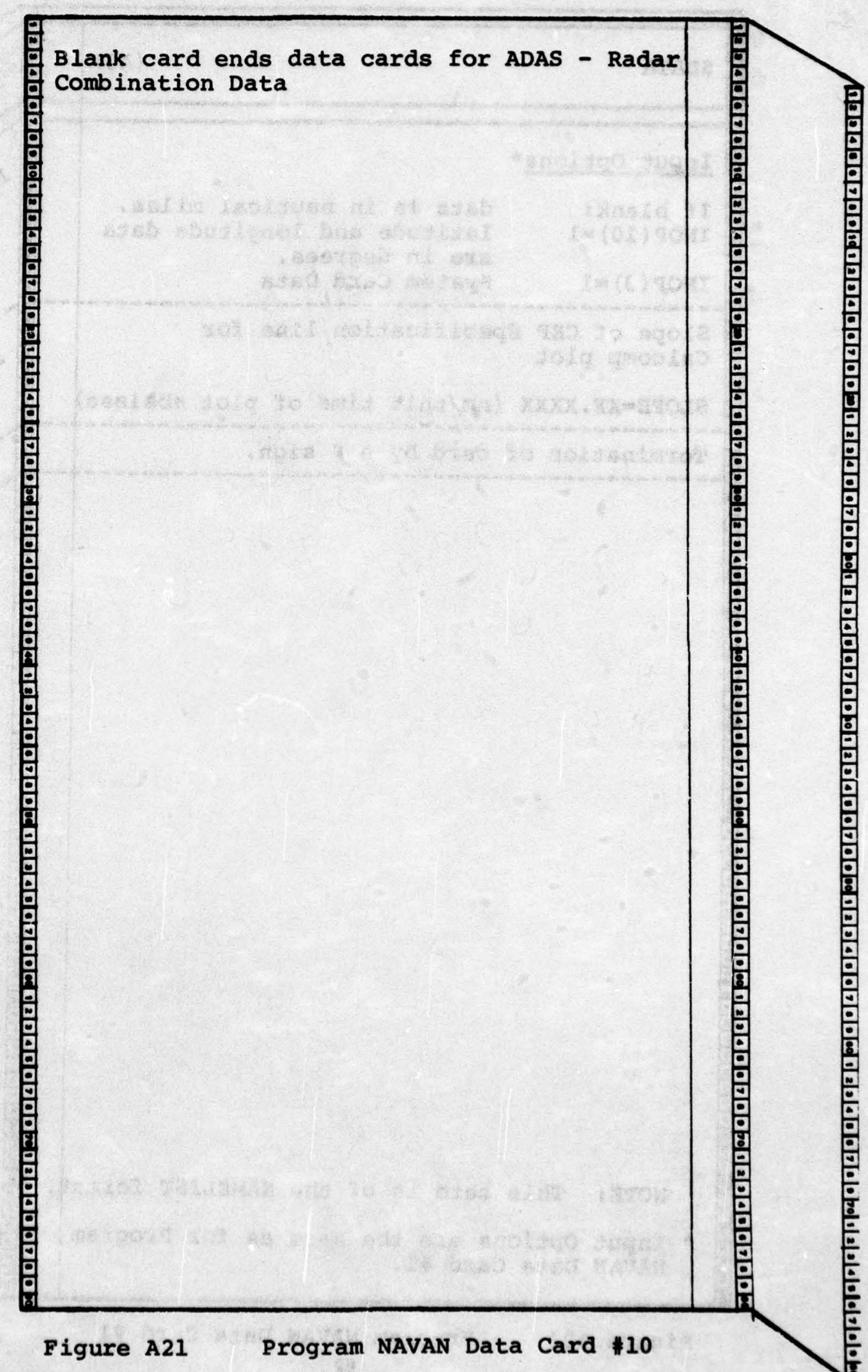


Figure A21 Program NAVAN Data Card #10

$DATA (A5)

<u>Input Options</u>*

If blank:	data is in nautical miles.
INOP(10)=1	latitude and longitude data are in degrees.
INOP(3)=1	System Card Data

Slope of CEP Specification line for Calcomp plot

SLOPE=XX.XXXX (nm/unit time of plot absissa)

Termination of card by a $ sign.

NOTE: This card is of the NAMELIST format.

* Input Options are the same as for Program NAVAN Data Card #1.

$DATA

INOP

SLOPE

$

Figure A22 Program NAVAN Data Card #1

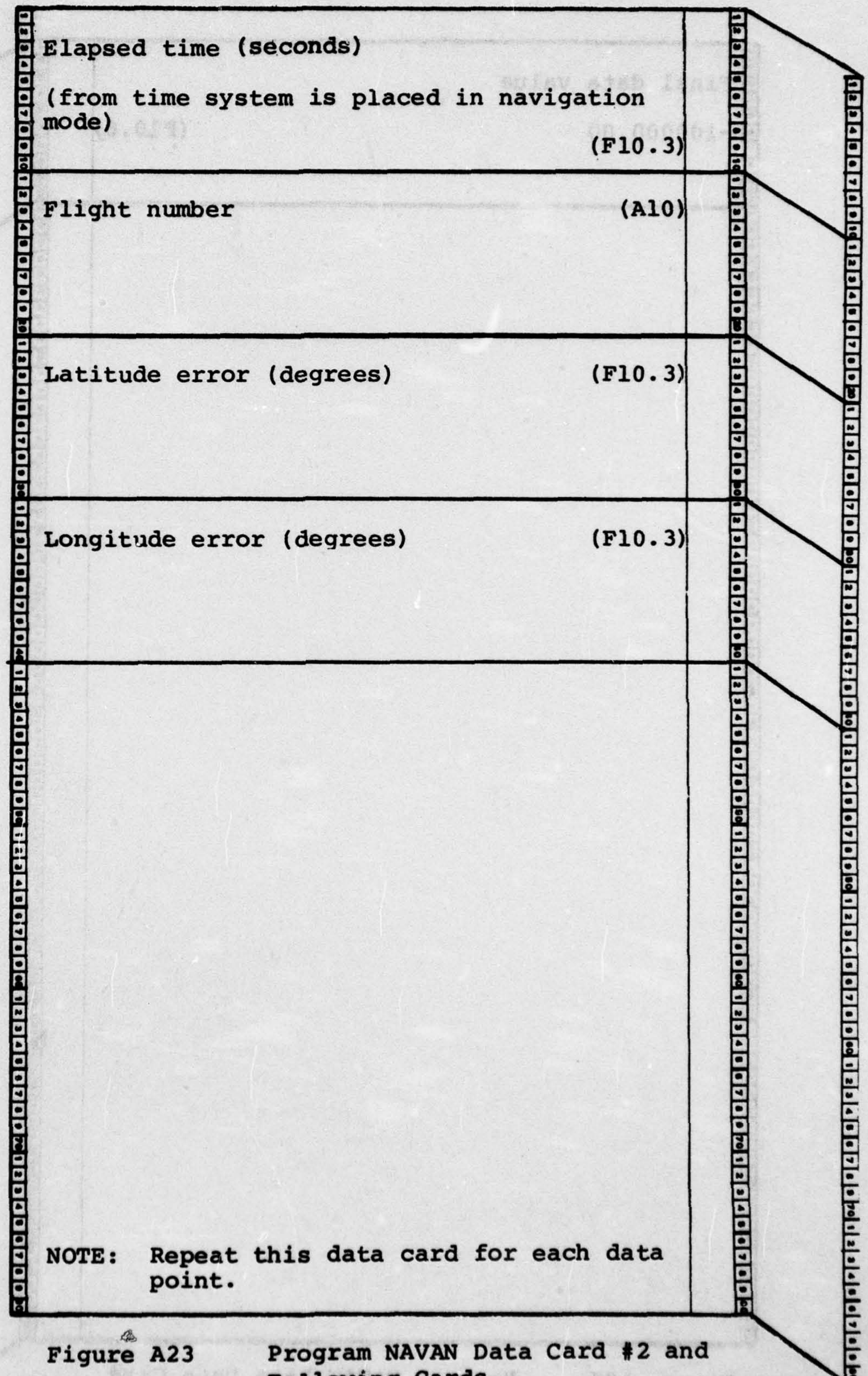


Figure A23 Program NAVAN Data Card #2 and Following Cards

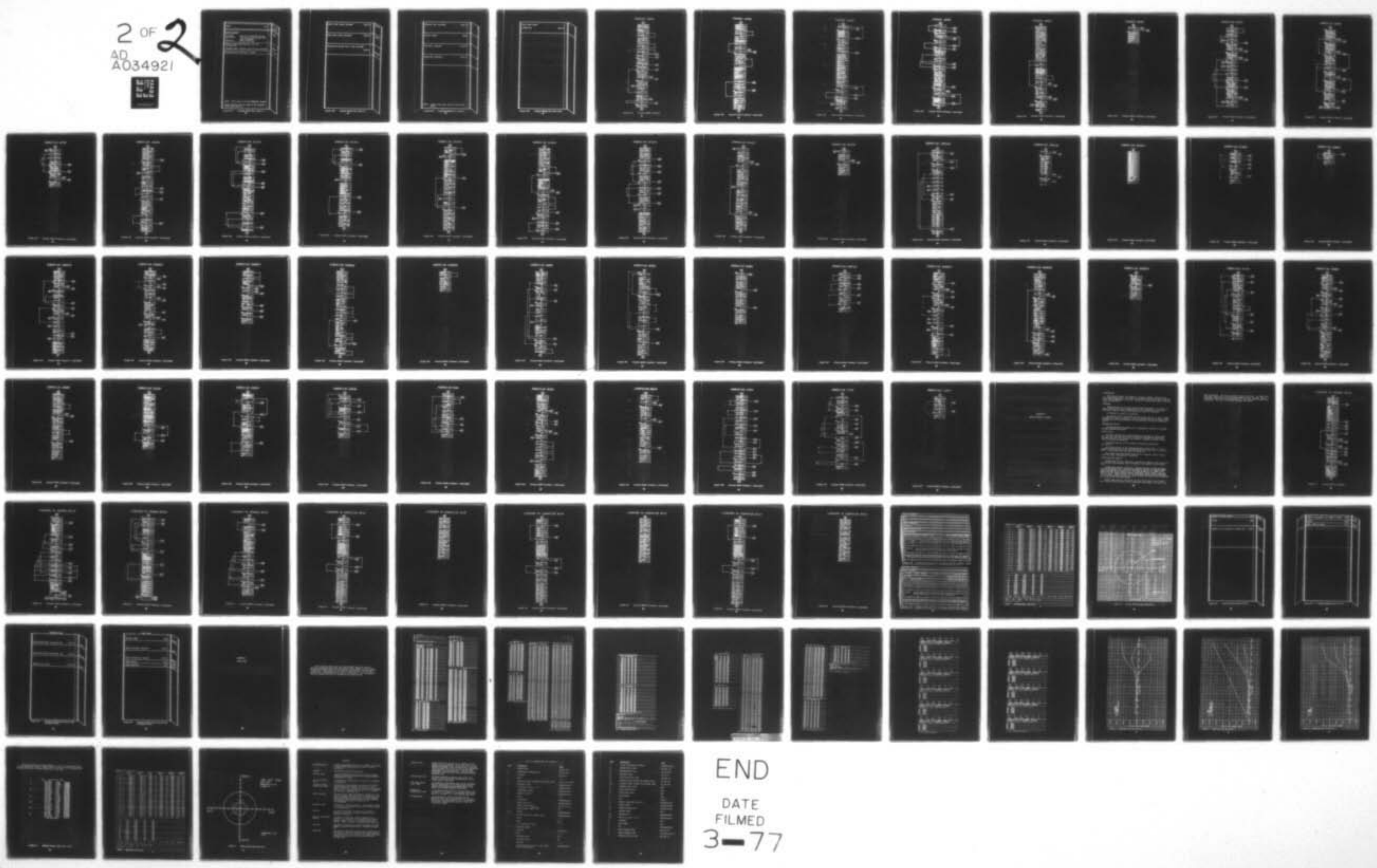
Final data value

-100000.00 (F10.0)

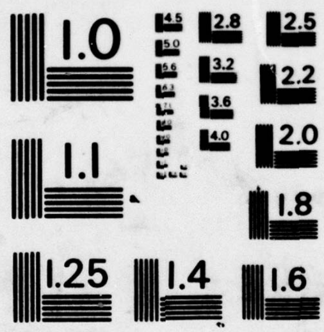
Figure A24 Program NAVAN Last Data Card

AD-A034 921 AIR FORCE FLIGHT TEST CENTER EDWARDS AFB CALIF F/G 17/7
INERTIAL NAVIGATION SYSTEMS TESTING HANDBOOKS.(U)
JUL 76 L D PLEWS, C W BRINKLEY, K E REESER
UNCLASSIFIED AFFTC-TIH-76-1 NL

2 OF 2
AD
A034921



END
DATE
FILMED
3-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

$DATA (A5)

Input Options*

If blank: data is in nautical miles.
INOP(10)=1 latitude and longitude data are in degrees.
INOP(4)=1 Radar Card Data

Slope of CEP Specification line for Calcomp plot

SLOPE=XX.XXXX (nm/unit time of plot absissa)

Termination of card by a $ sign.

NOTE: This card is of the NAMELIST format.

* Input Options are the same as for Program NAVAN Data Card #1.

Figure A25 Program NAVAN Data Card #1

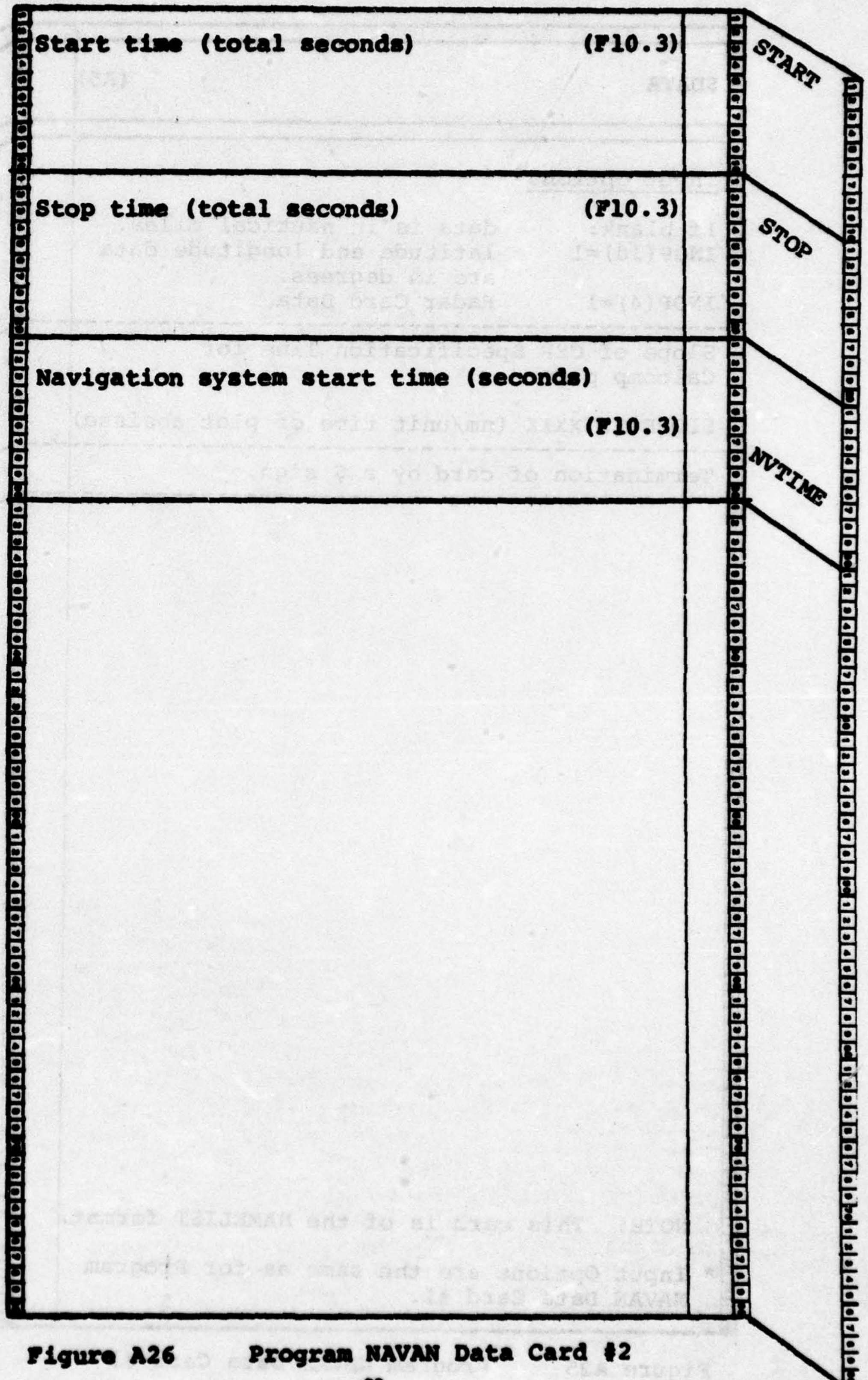


Figure A26   Program NAVAN Data Card #2

Elapsed time (seconds)	**(F10.3)**
Flight number	**(A10)**
Latitude (degrees)	**(F10.3)**
Longitude (degrees)	**(F10.3)**

NOTE: Repeat this data card for each data point.

Figure A27 Program NAVAN Data Card #3

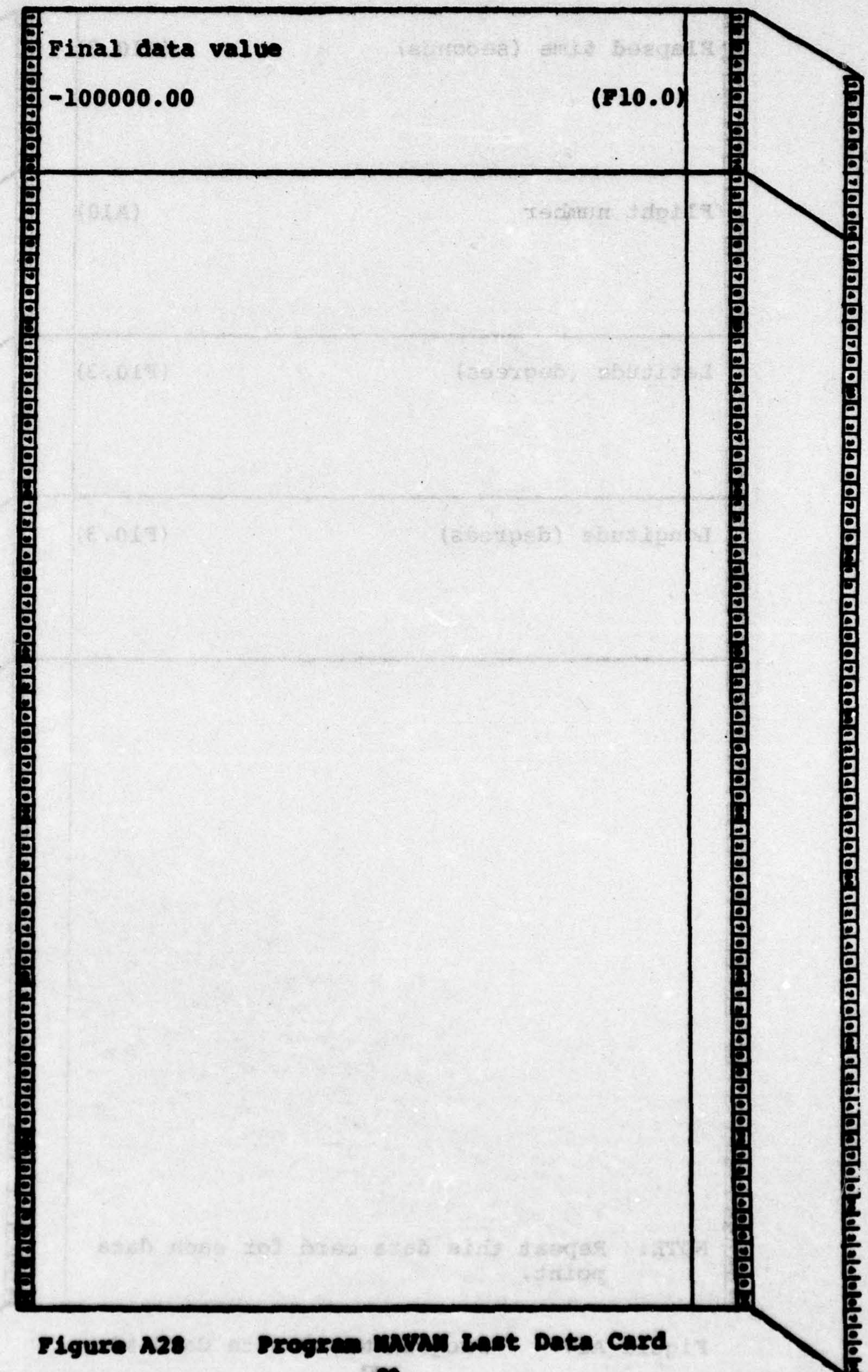


Figure A28   Program NAVAN Last Data Card

PROGRAM NAVAN

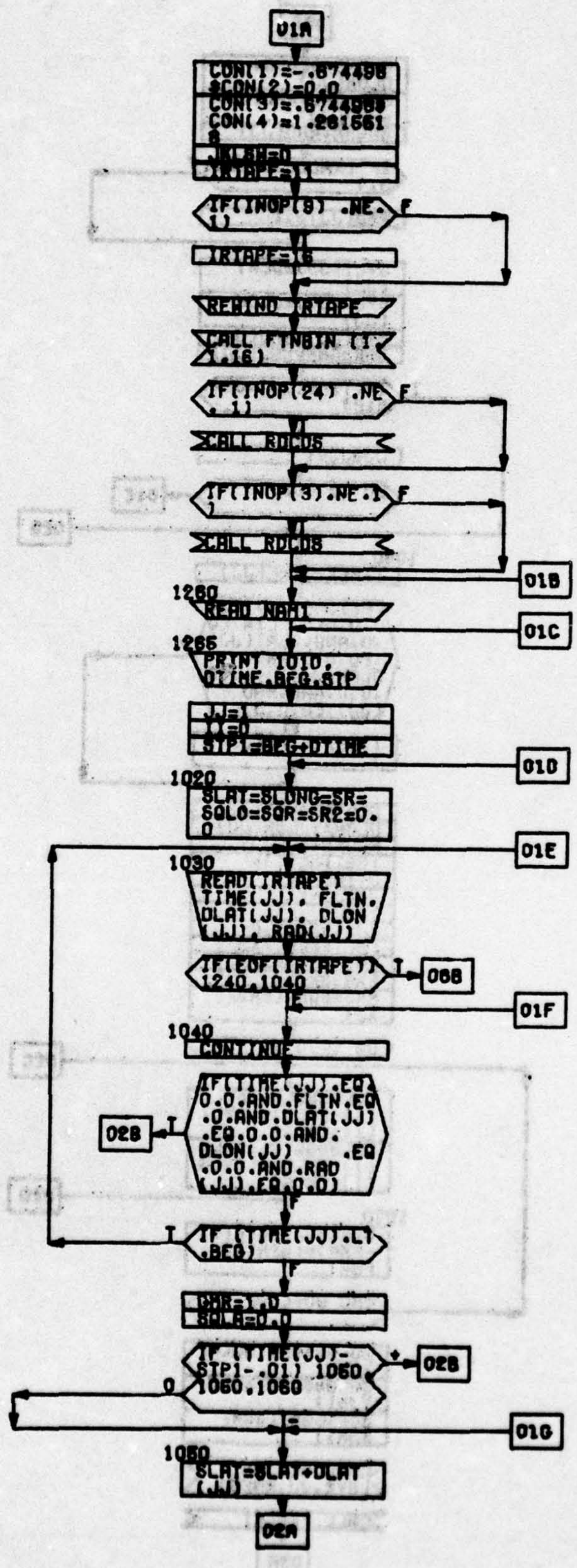


Figure A29 Program NAVAN Flowchart

PROGRAM NAVAN

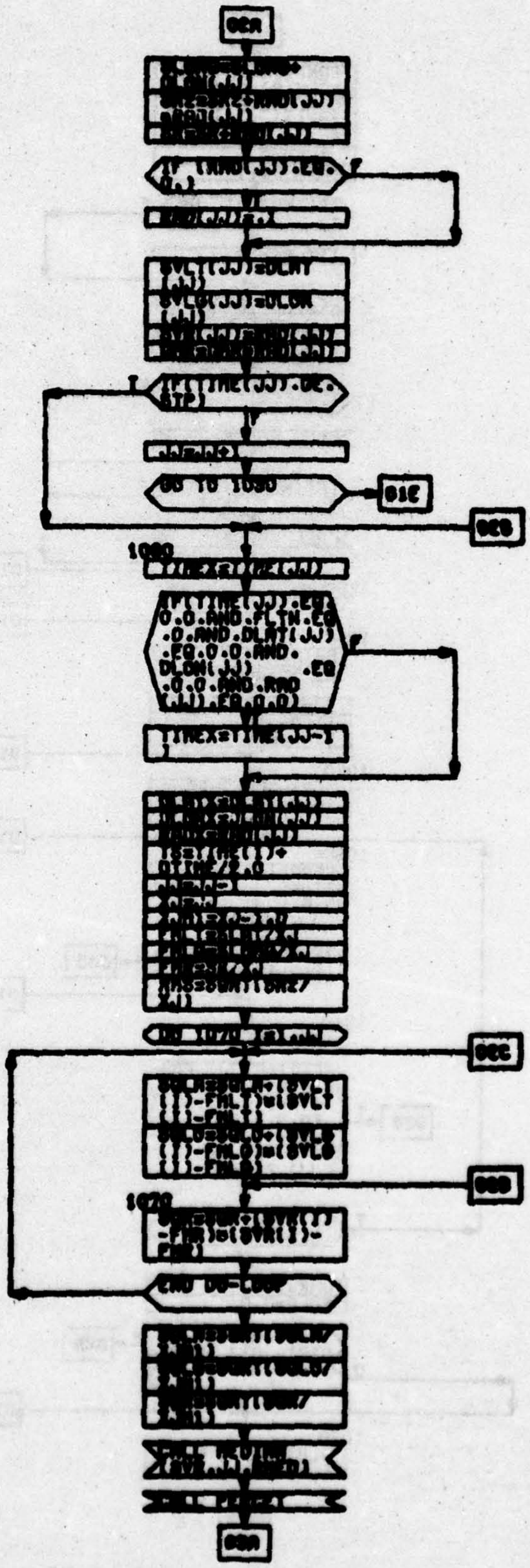


Figure A29 Program NAVAN Flowchart (continued)

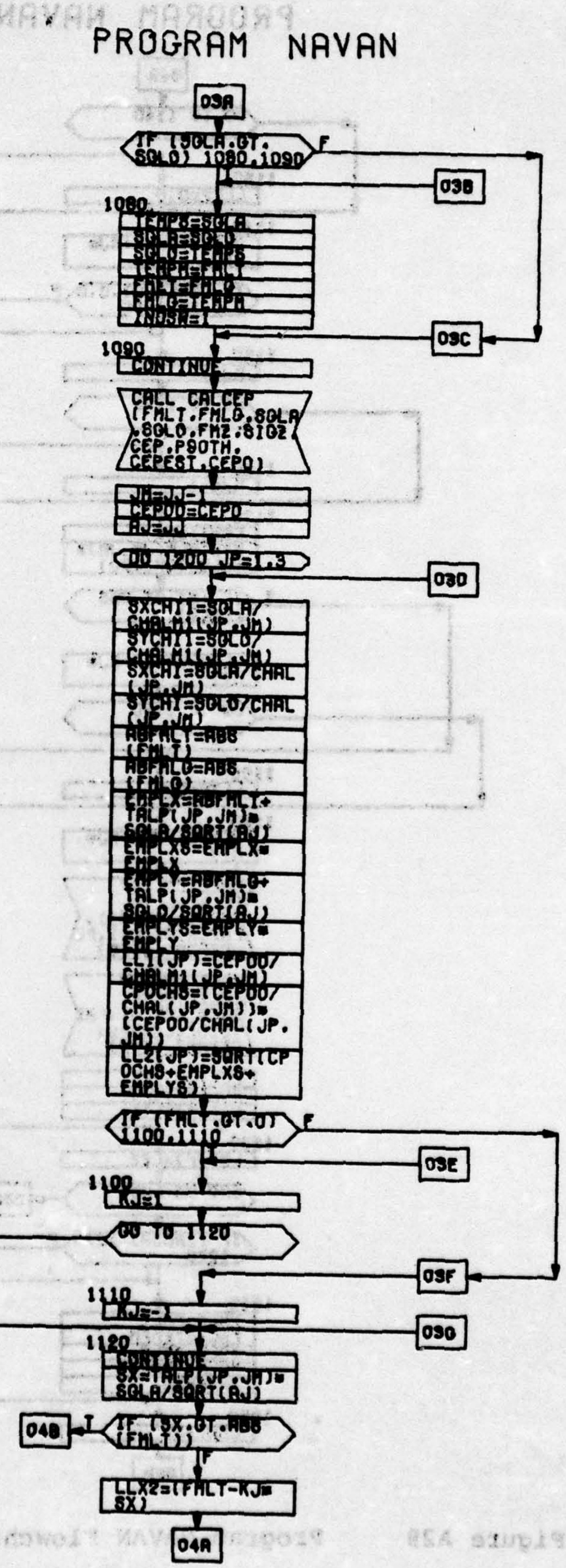


Figure A29 Program NAVAN Flowchart (continued)

PROGRAM NAVAN

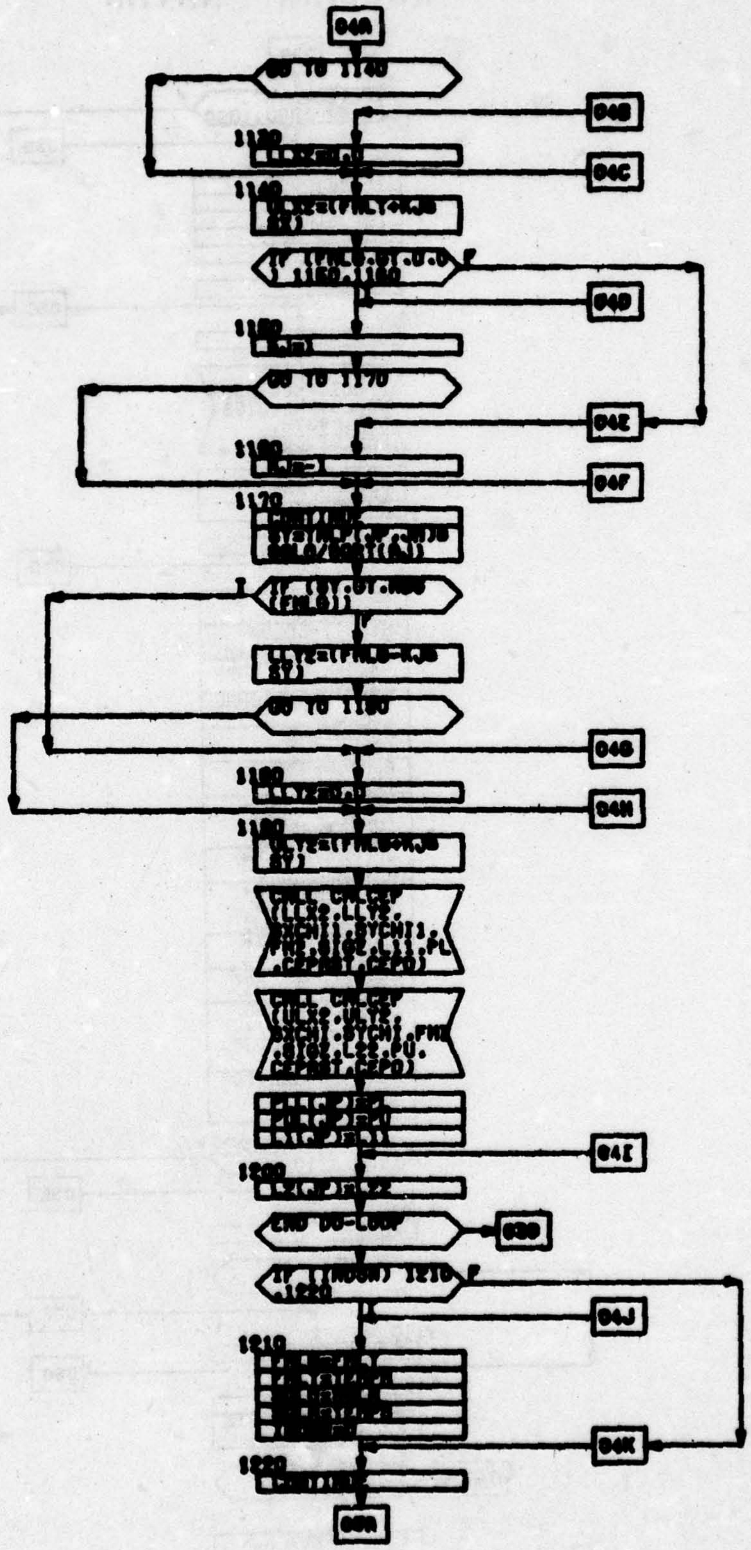


Figure A29 Program NAVAN Flowchart (continued)

PROGRAM NAVAN

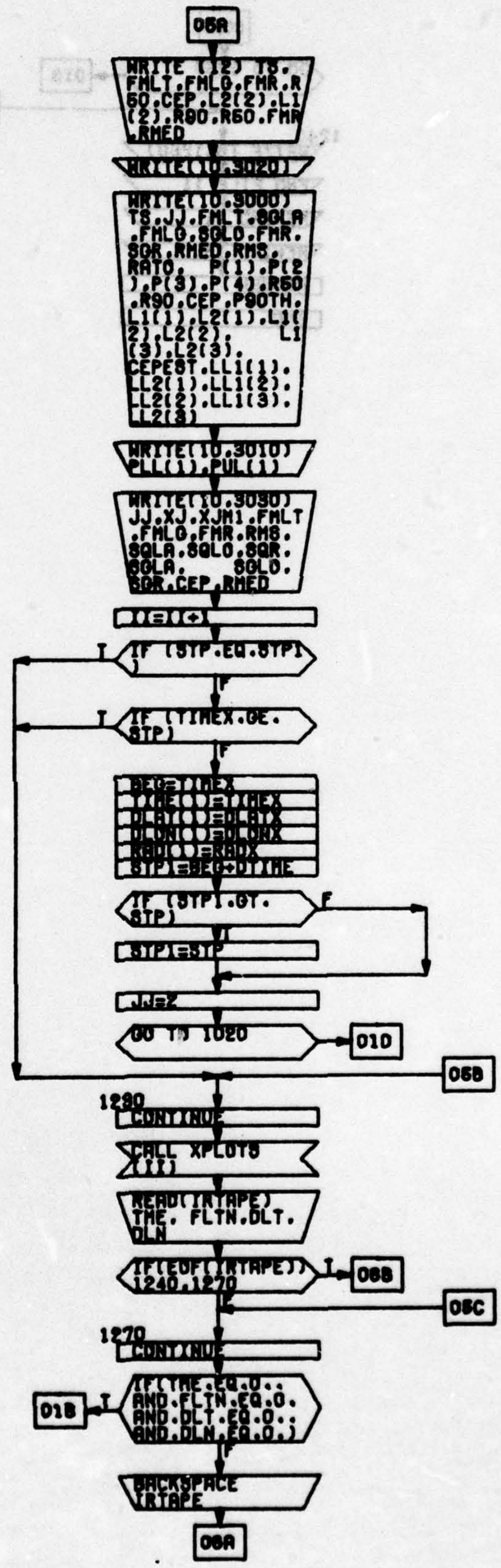


Figure A29 Program NAVAN Flowchart (continued)

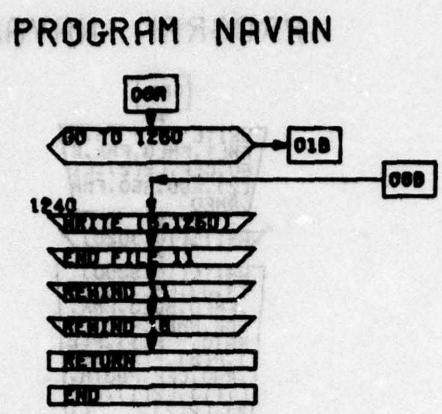


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE NAVMR

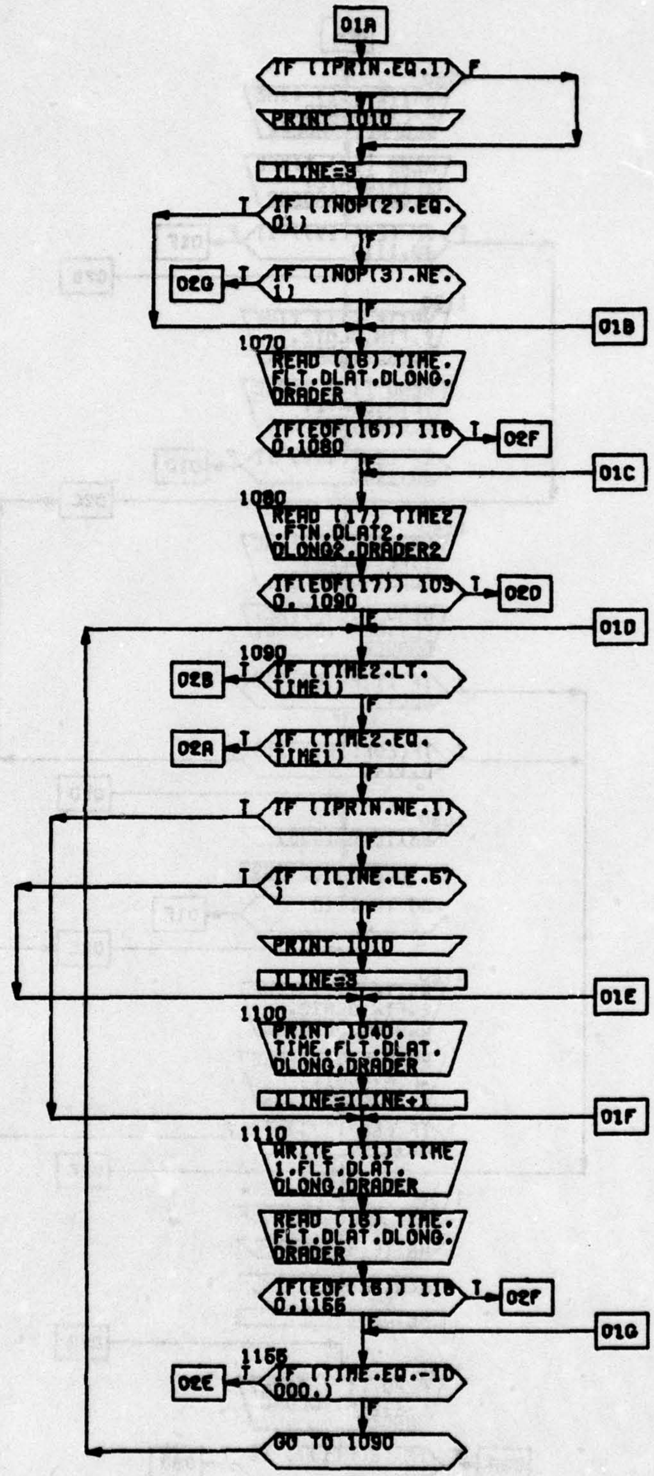


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE NAVMR

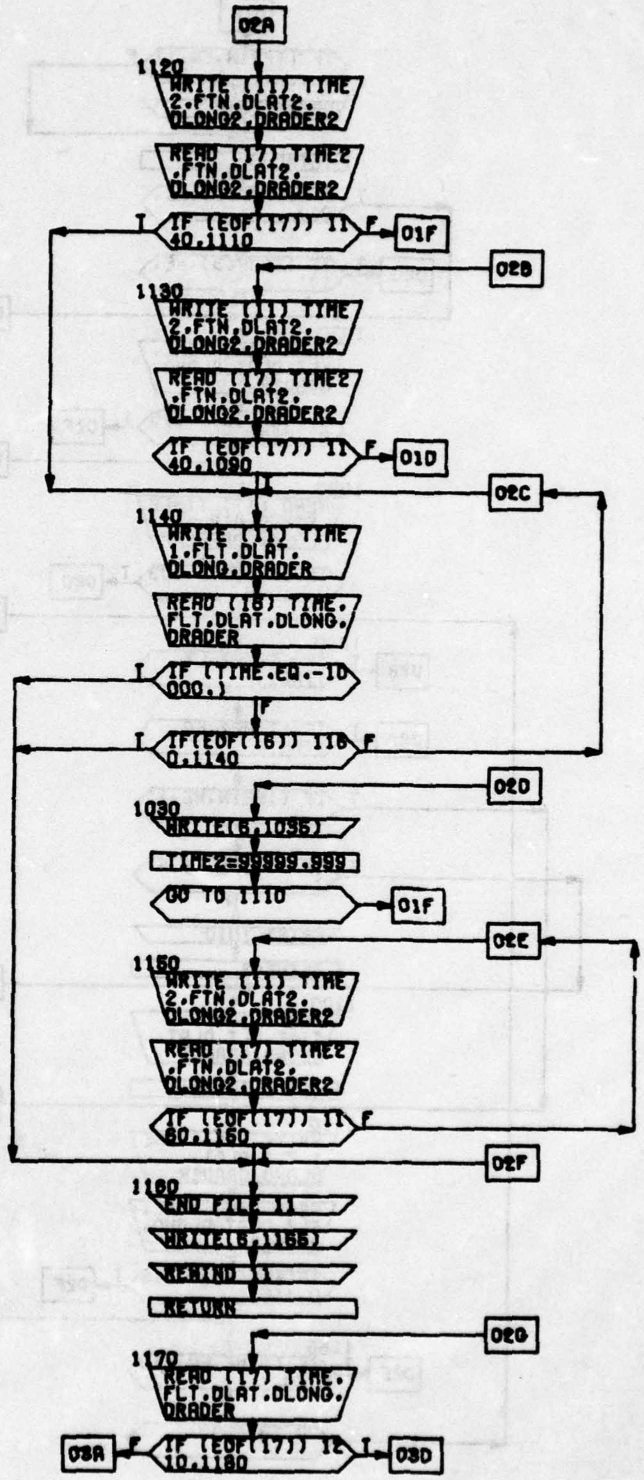


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE NAVMR

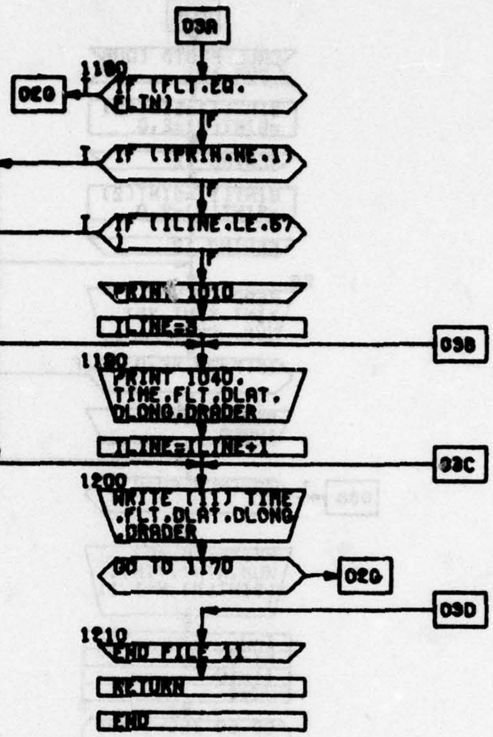


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

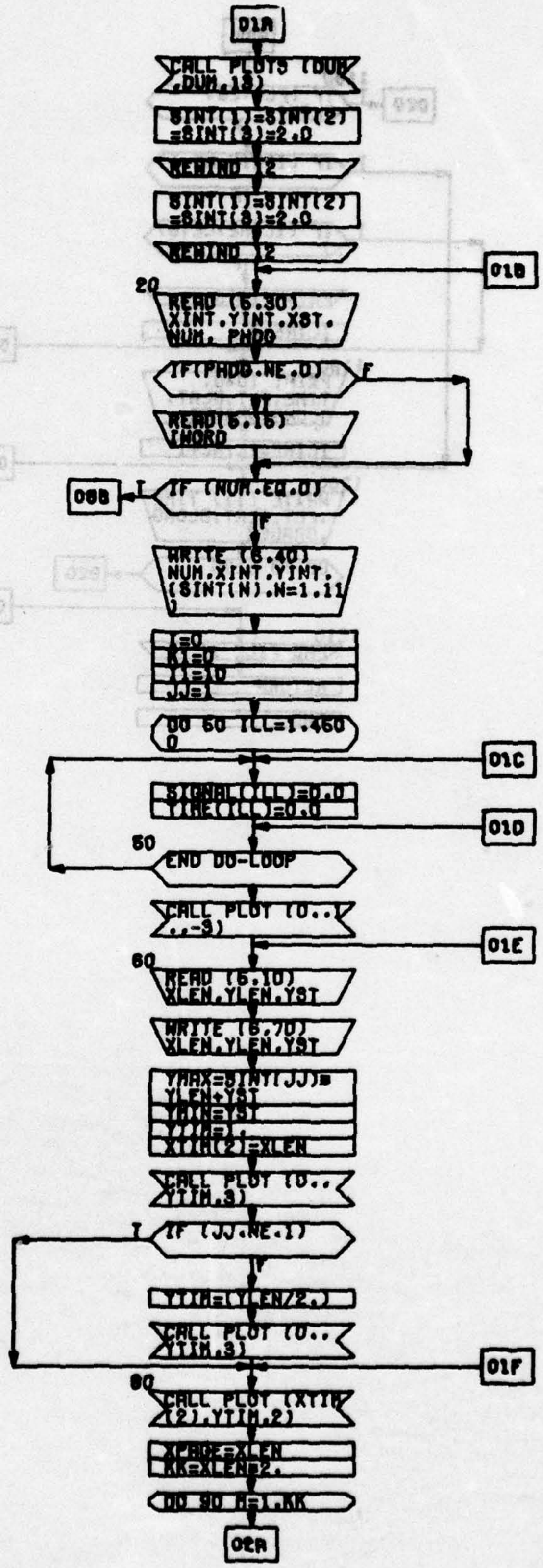


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

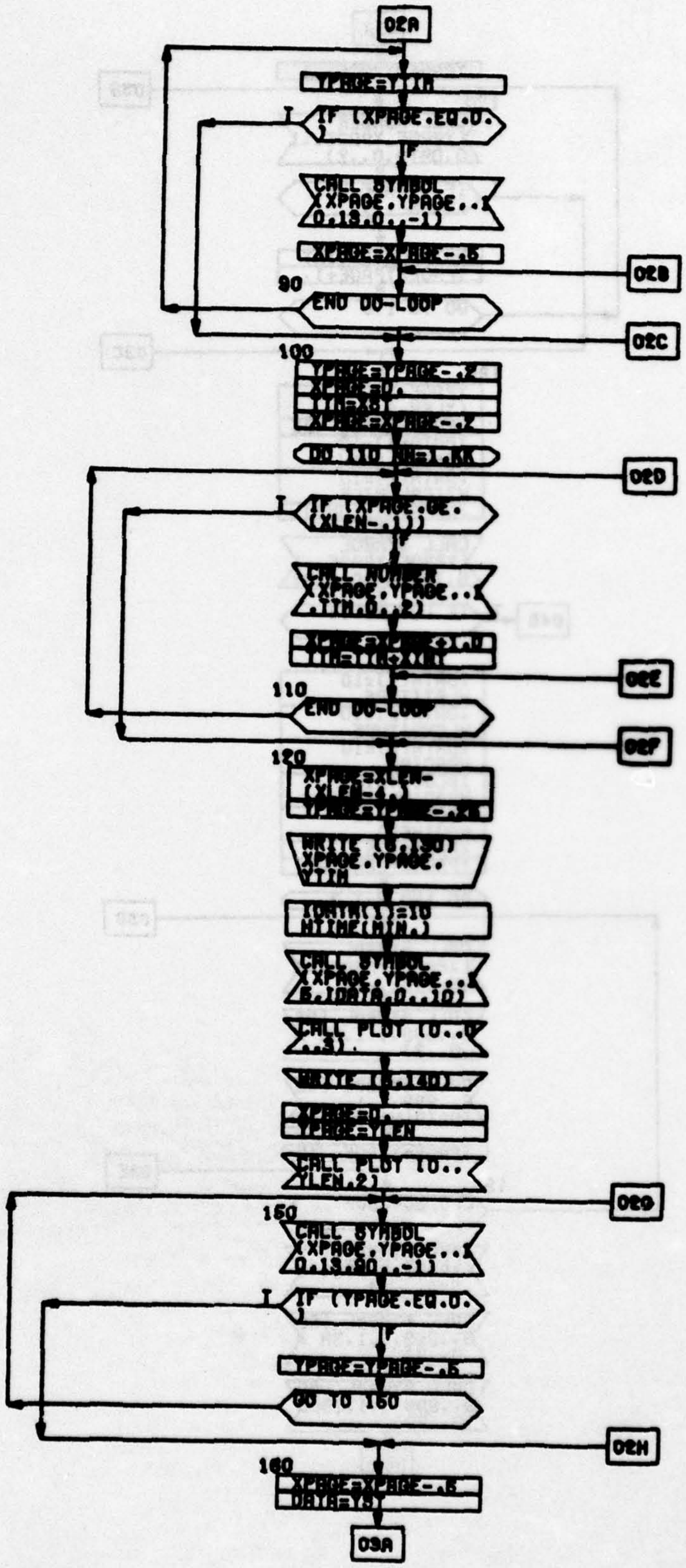


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

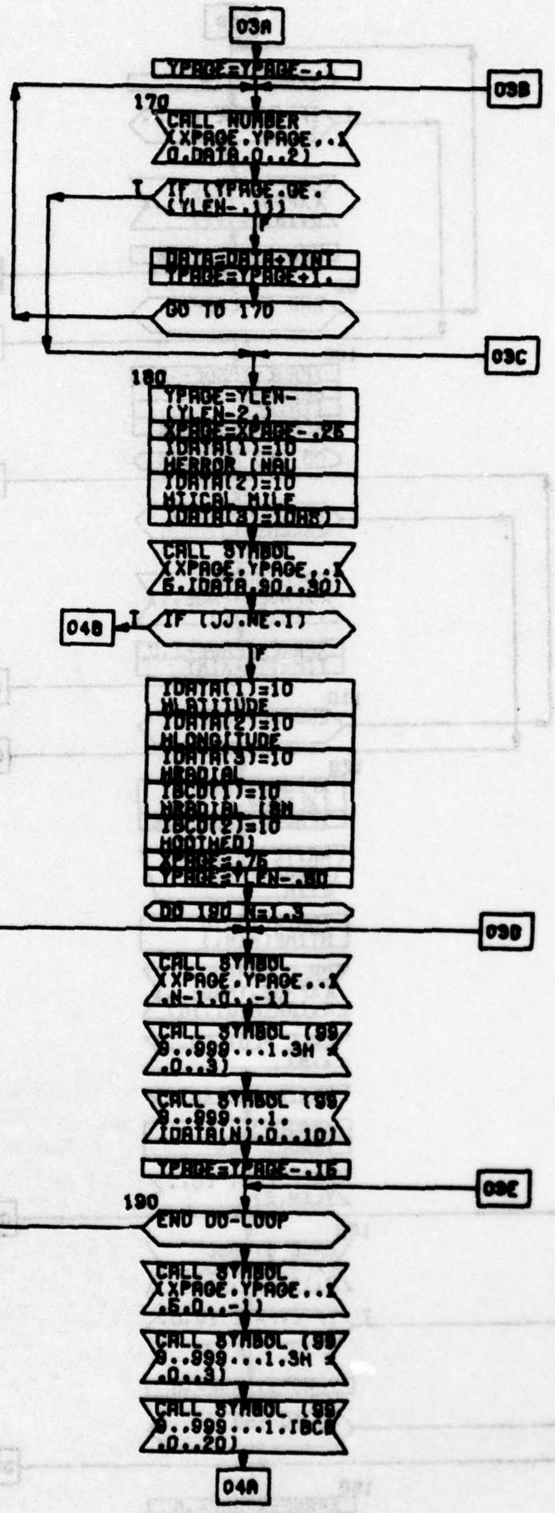


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

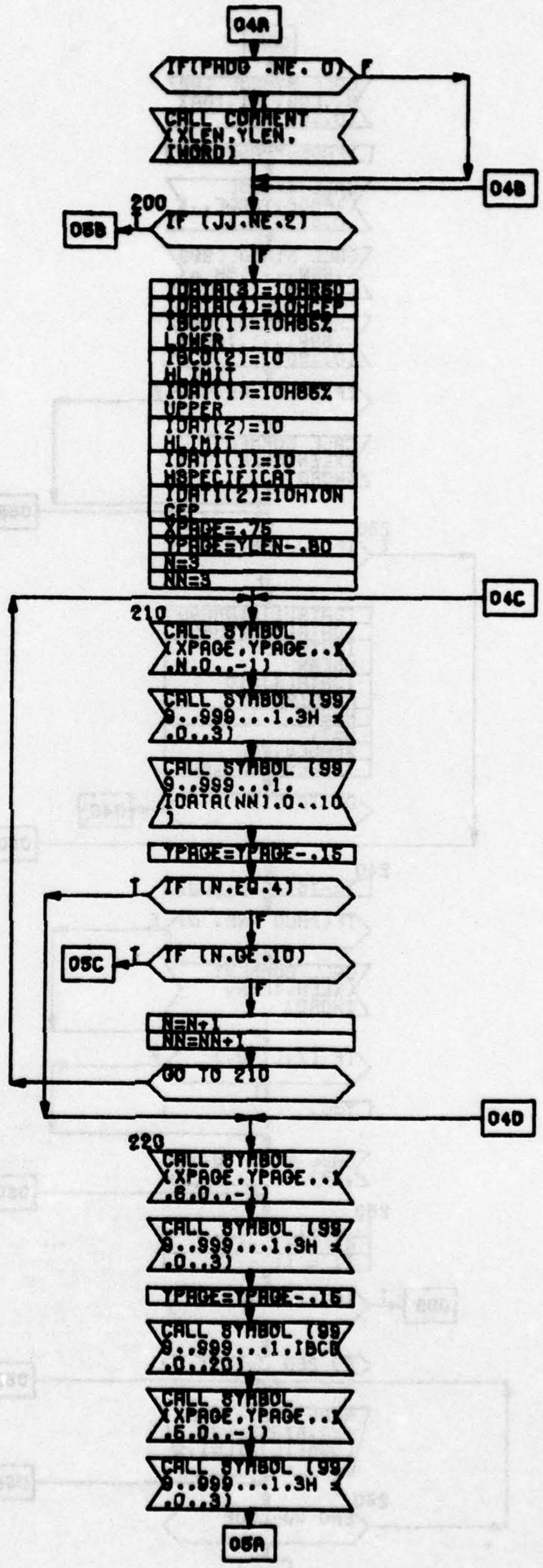


Figure A29 **Program NAVAN Flowchart (continued)**

SUBROUTINE XPLOTS

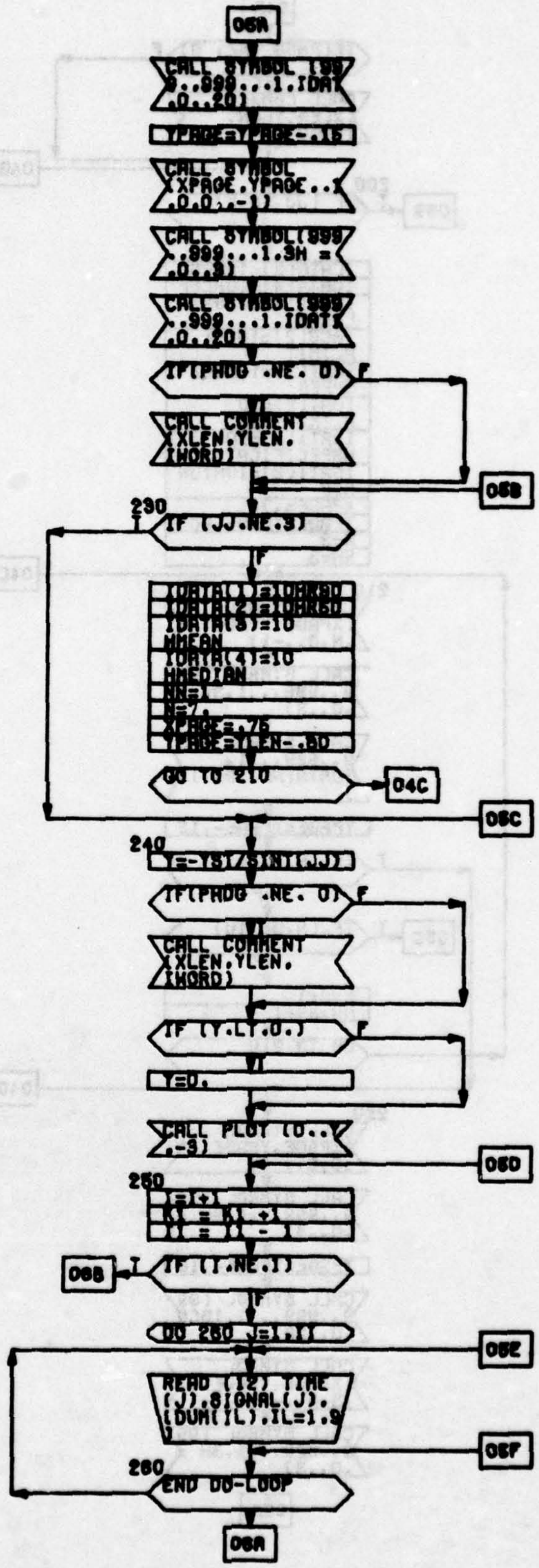


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

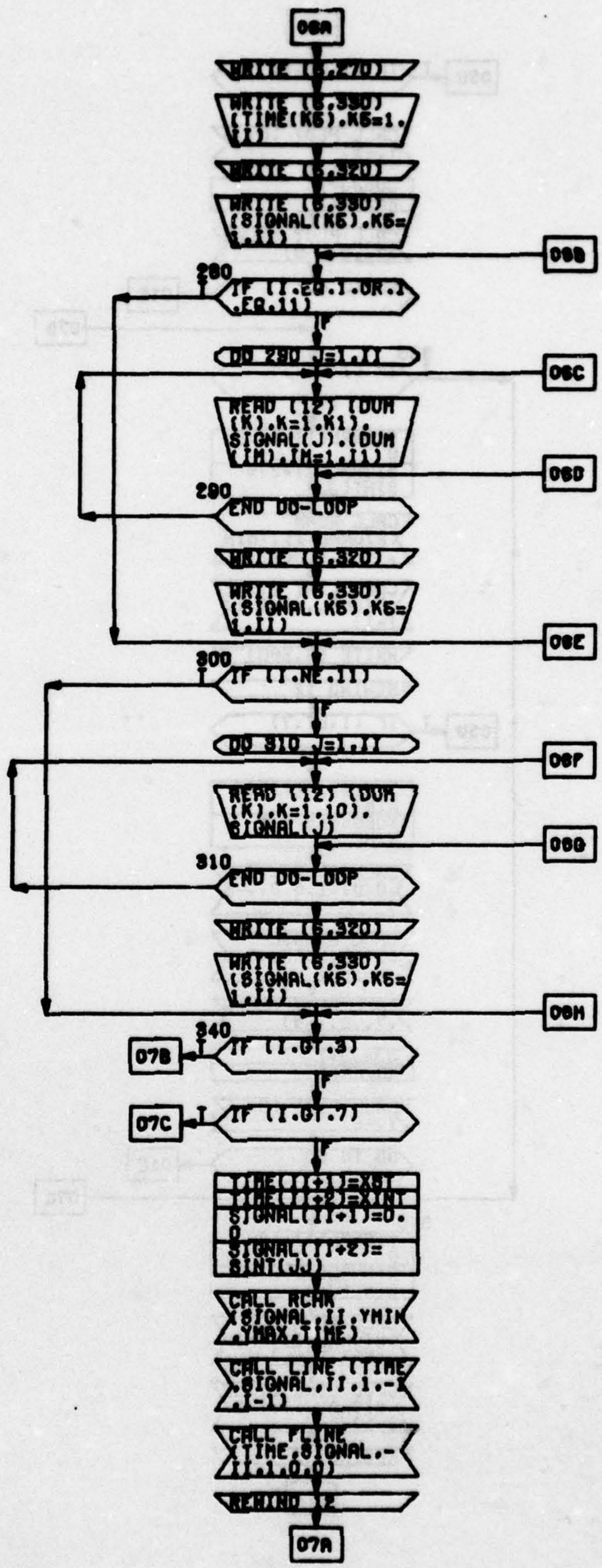


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

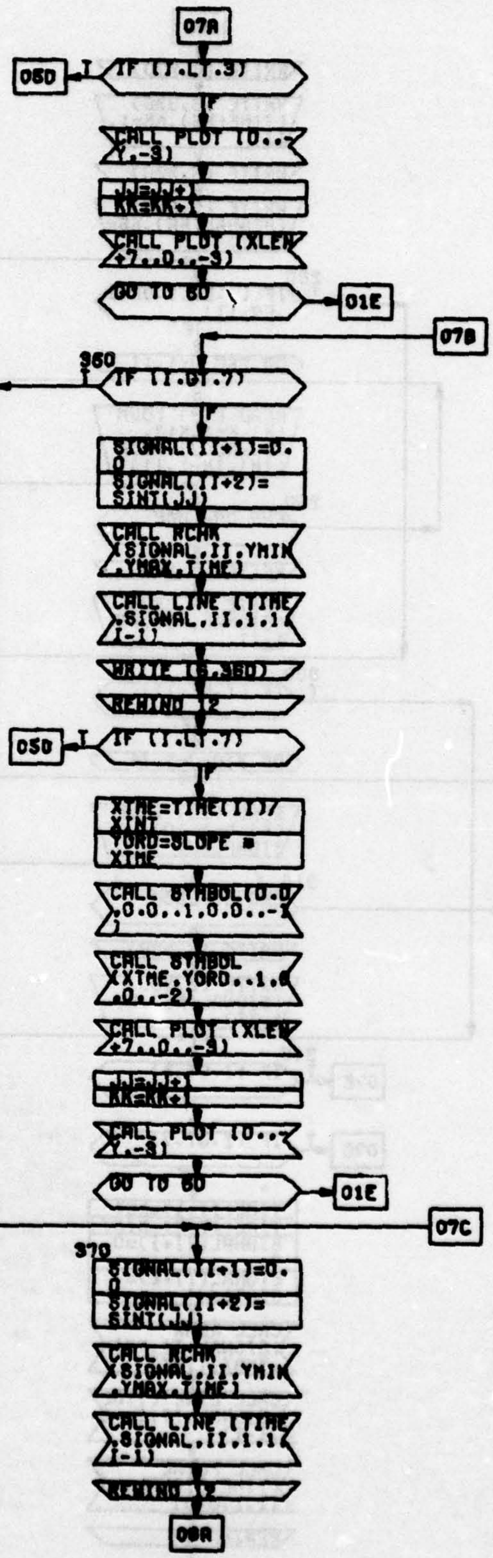


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE XPLOTS

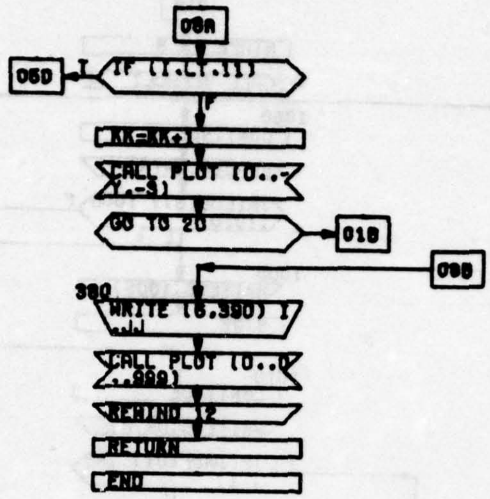


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE TAPELOG

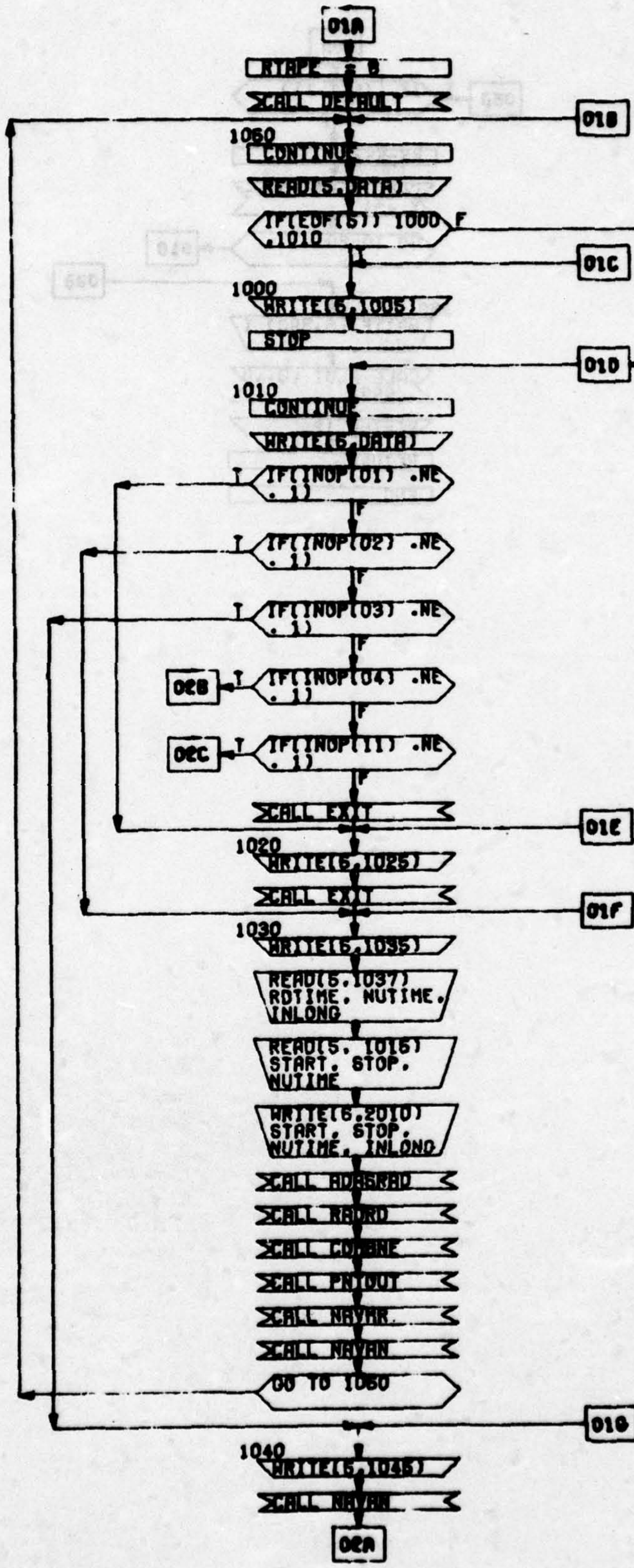


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE TAPELOG

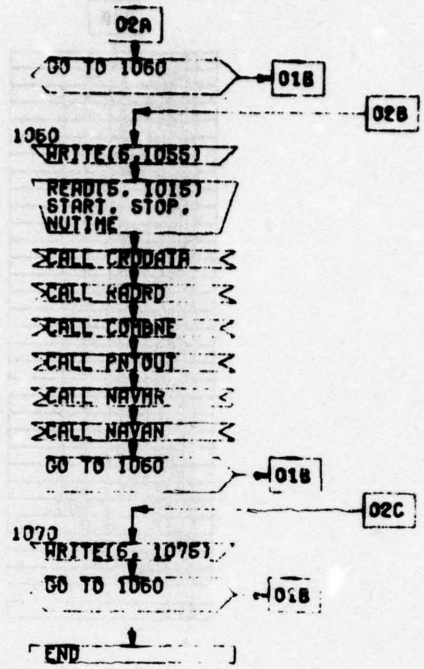


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE DEFAULT

Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE EXTRACT

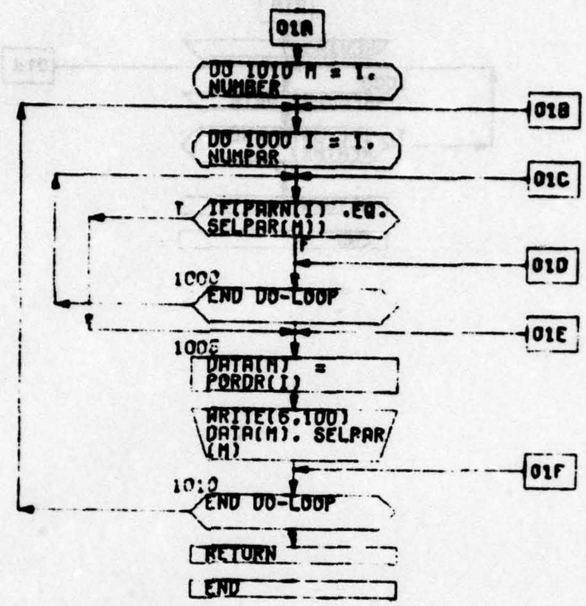


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE GOBACK

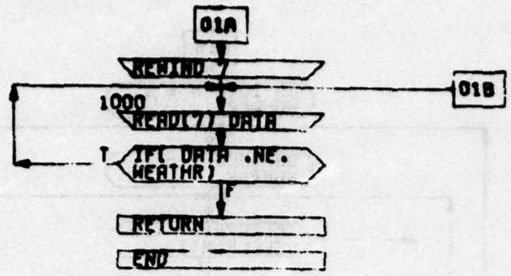


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE ADADATA

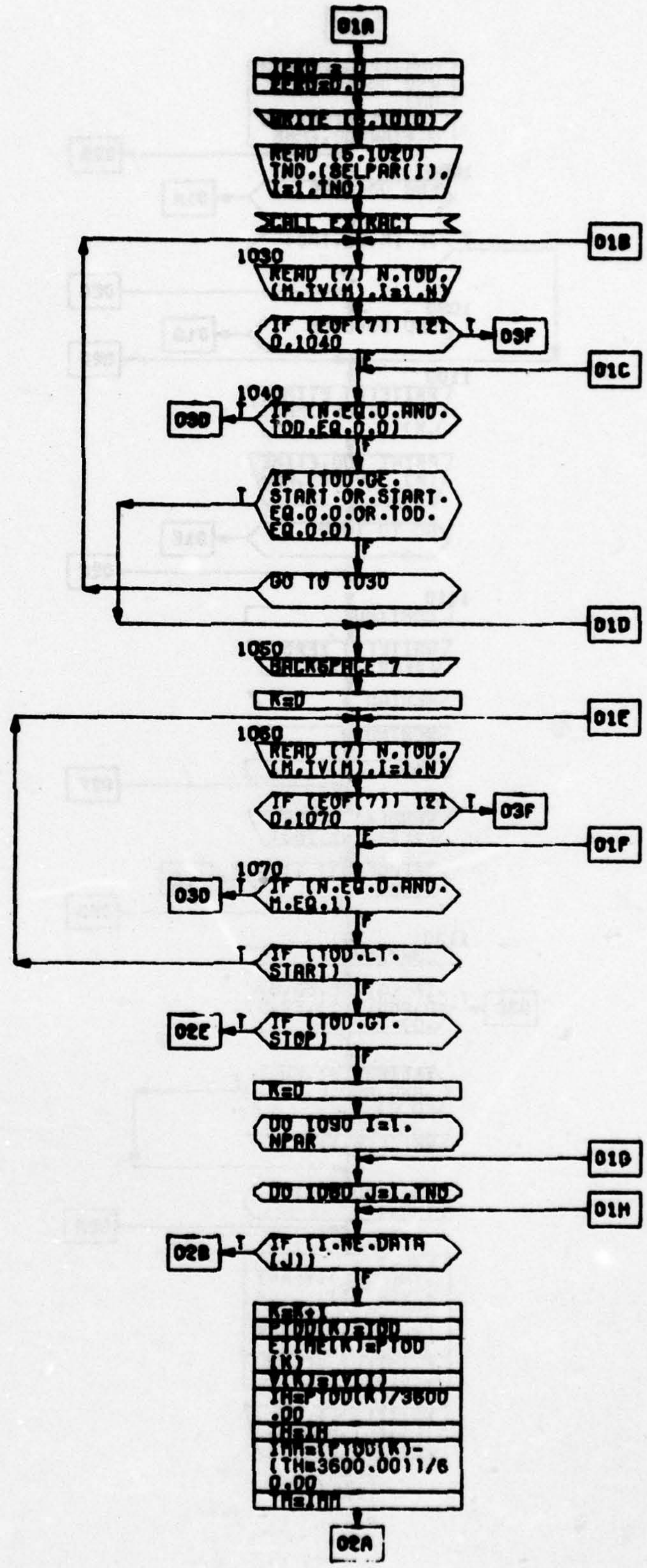


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE ADADATA

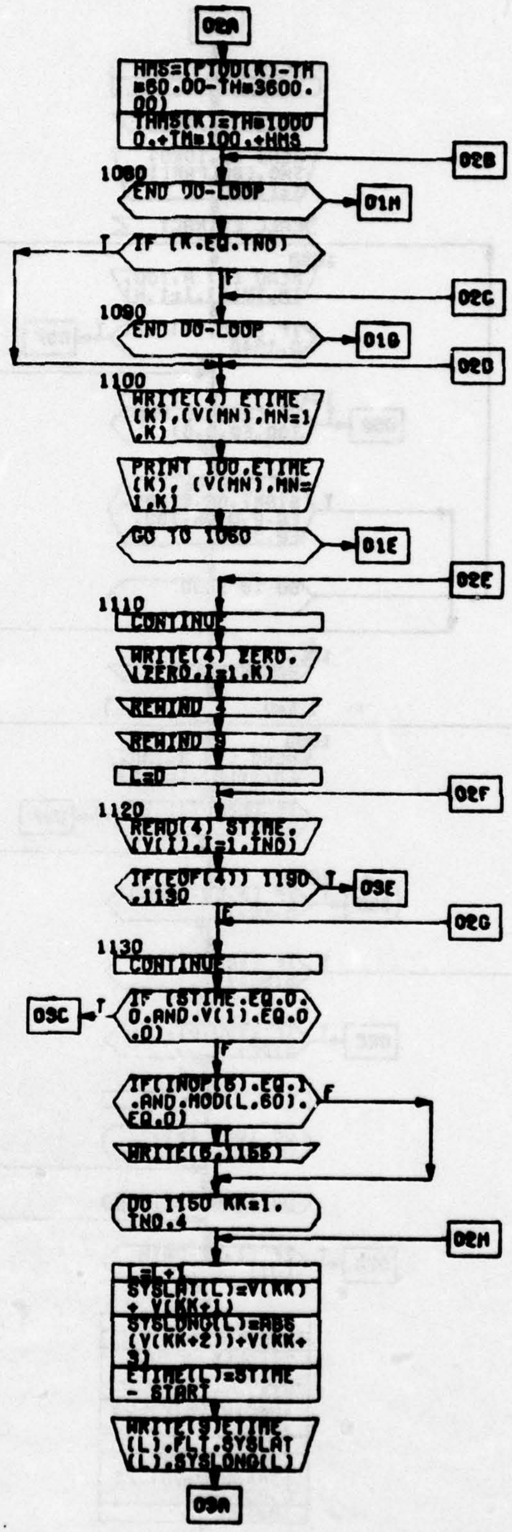


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE ADADATA

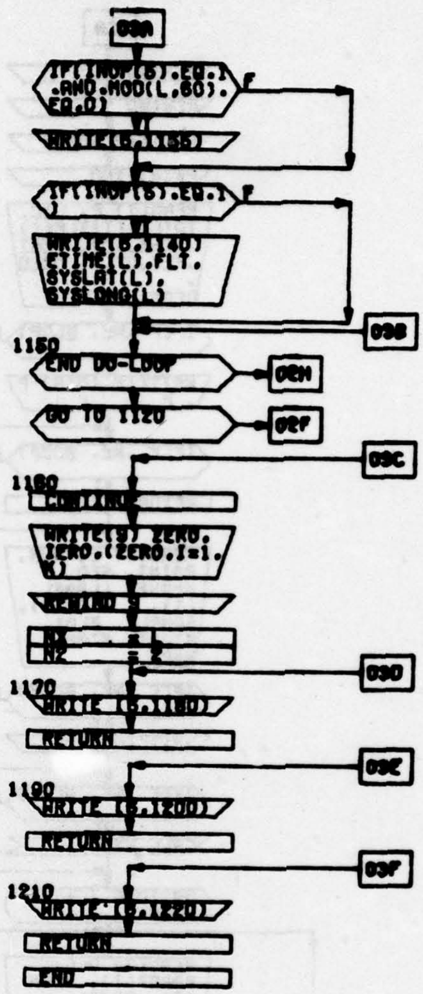


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE ADASRAD

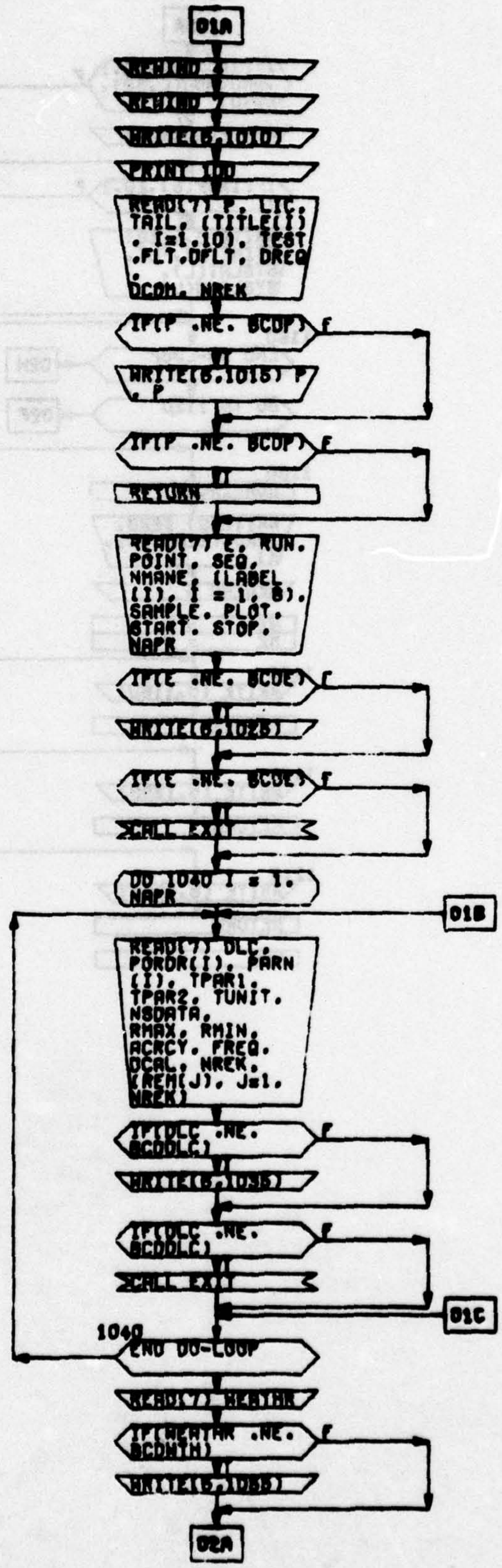


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE ADASRAD

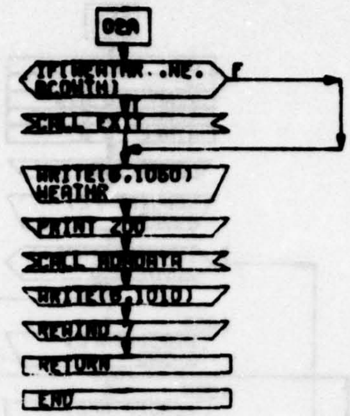


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE RADRD

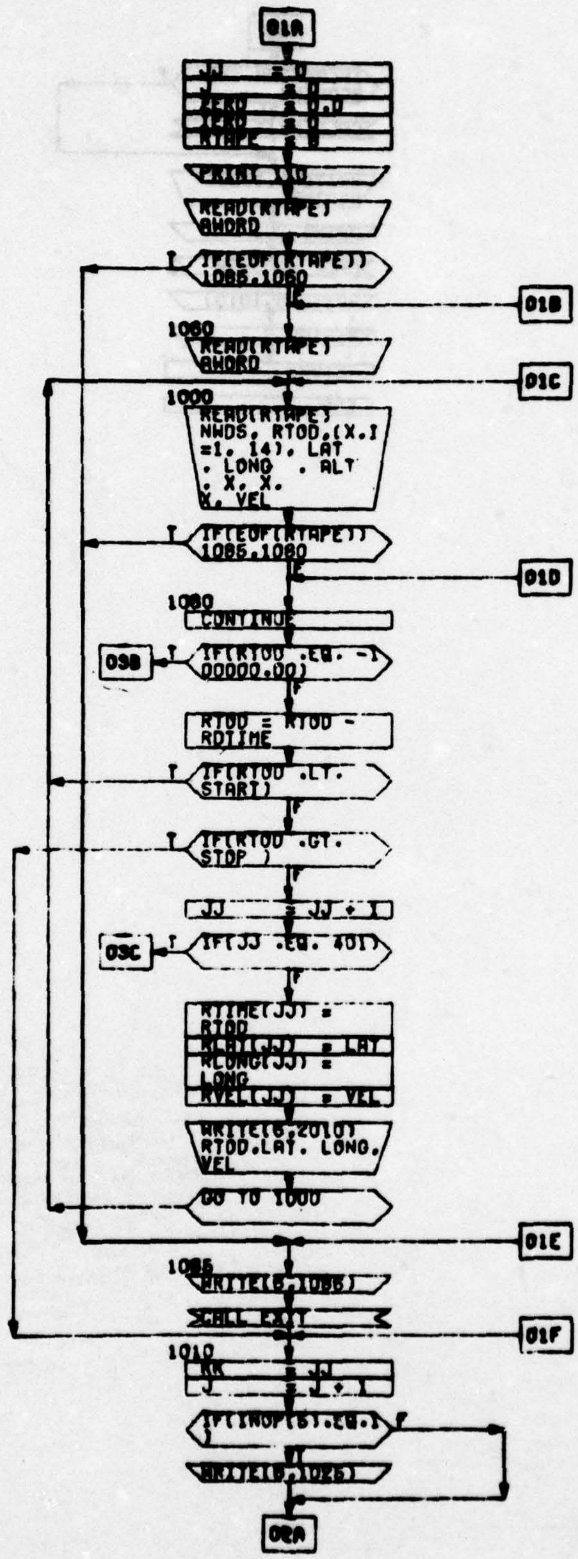


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE RADRD

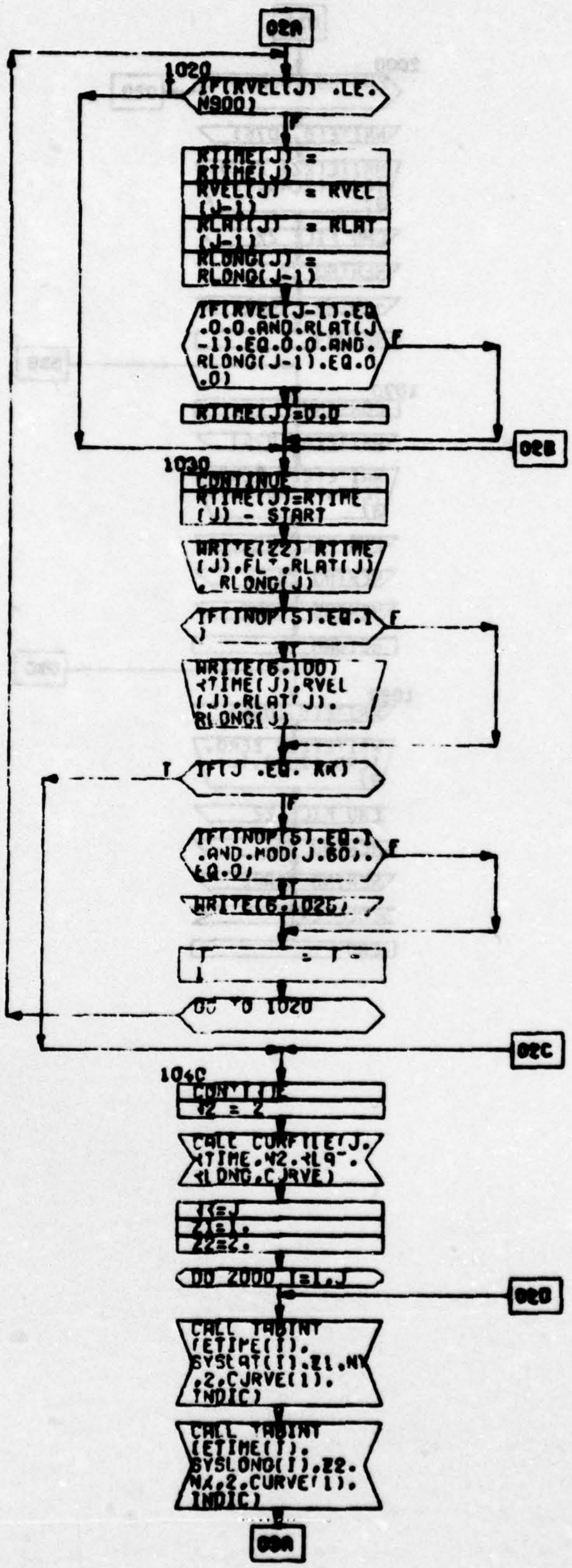


Figure A29 **Program NAVAN Flowchart (continued)**

SUBROUTINE RADRD

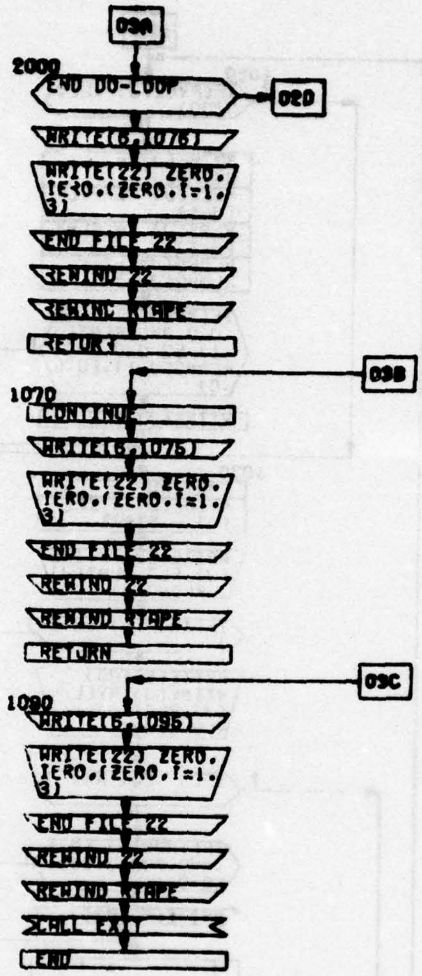


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE CURFILE

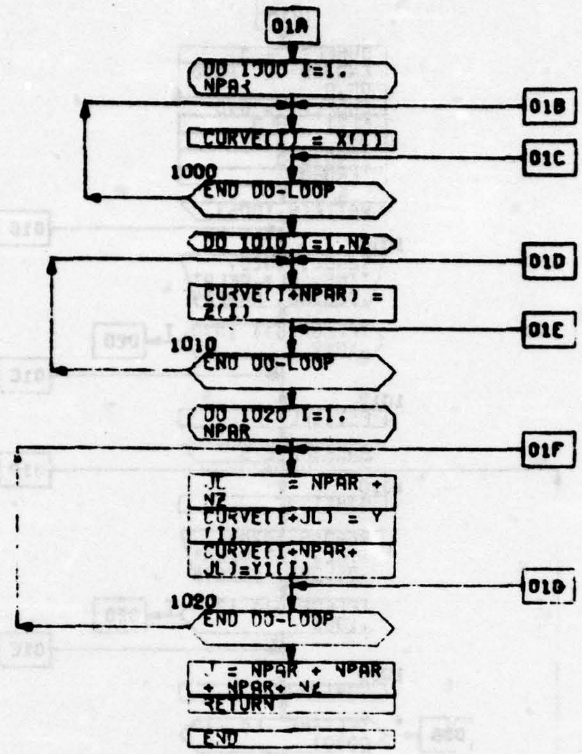


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE CRDDATA

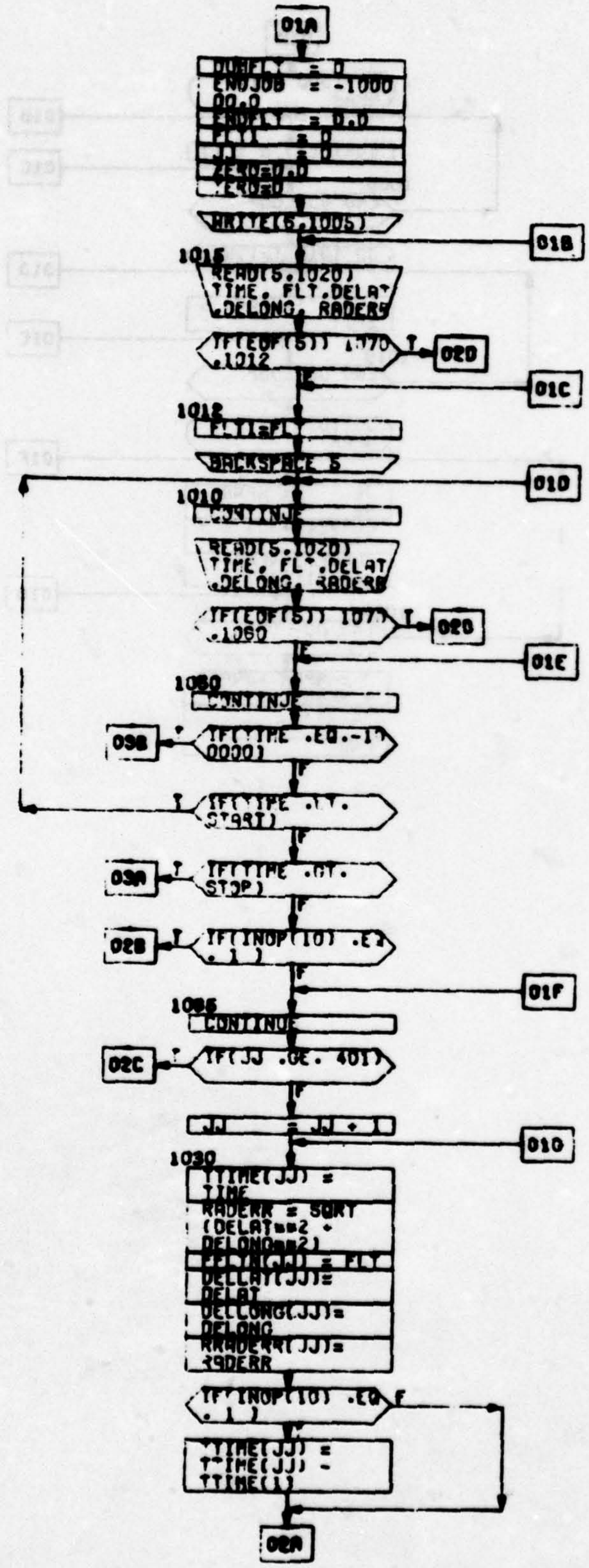


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE CRDDATA

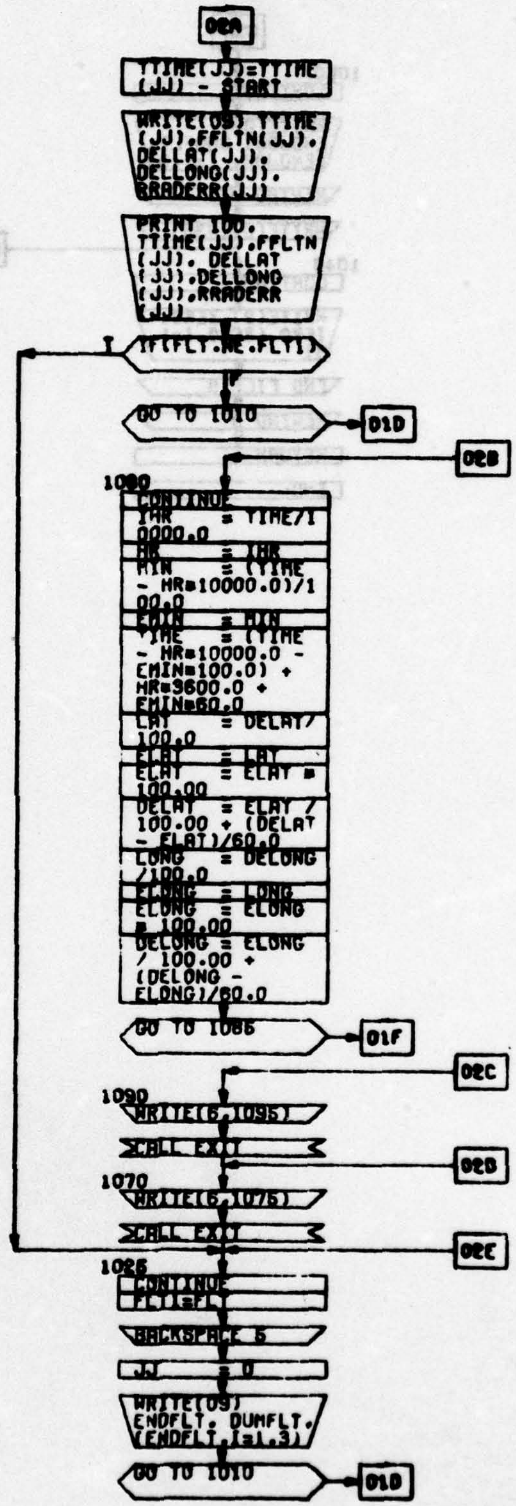


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE CRODATA

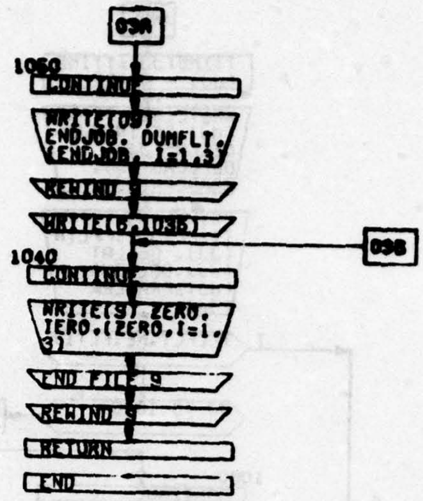


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE PNTOUT

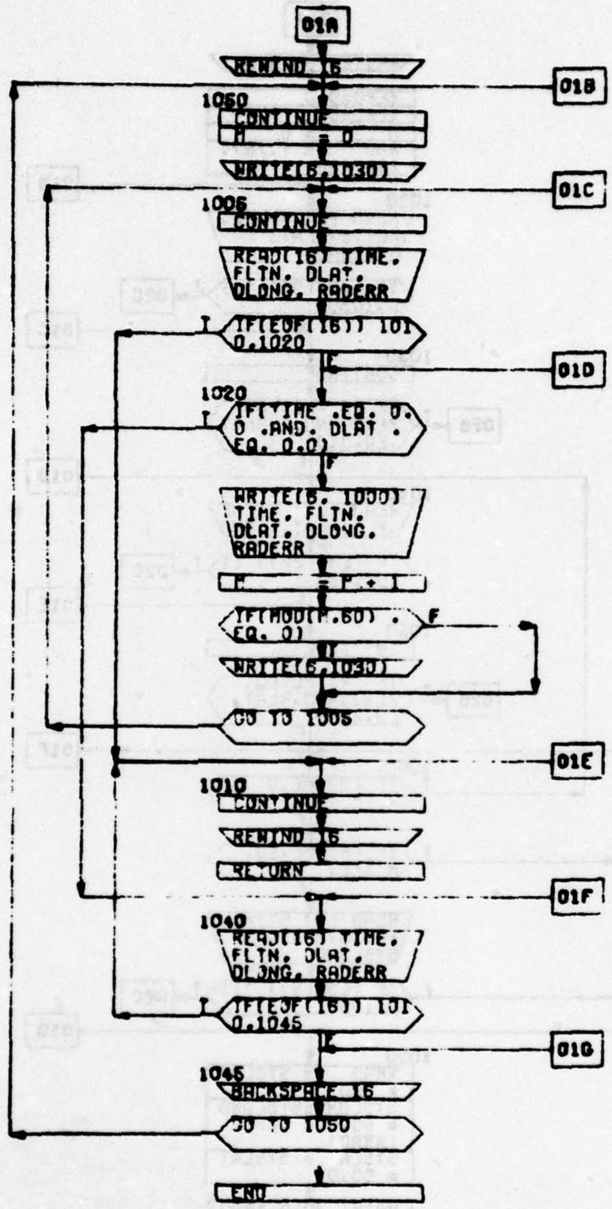


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE COMBNE

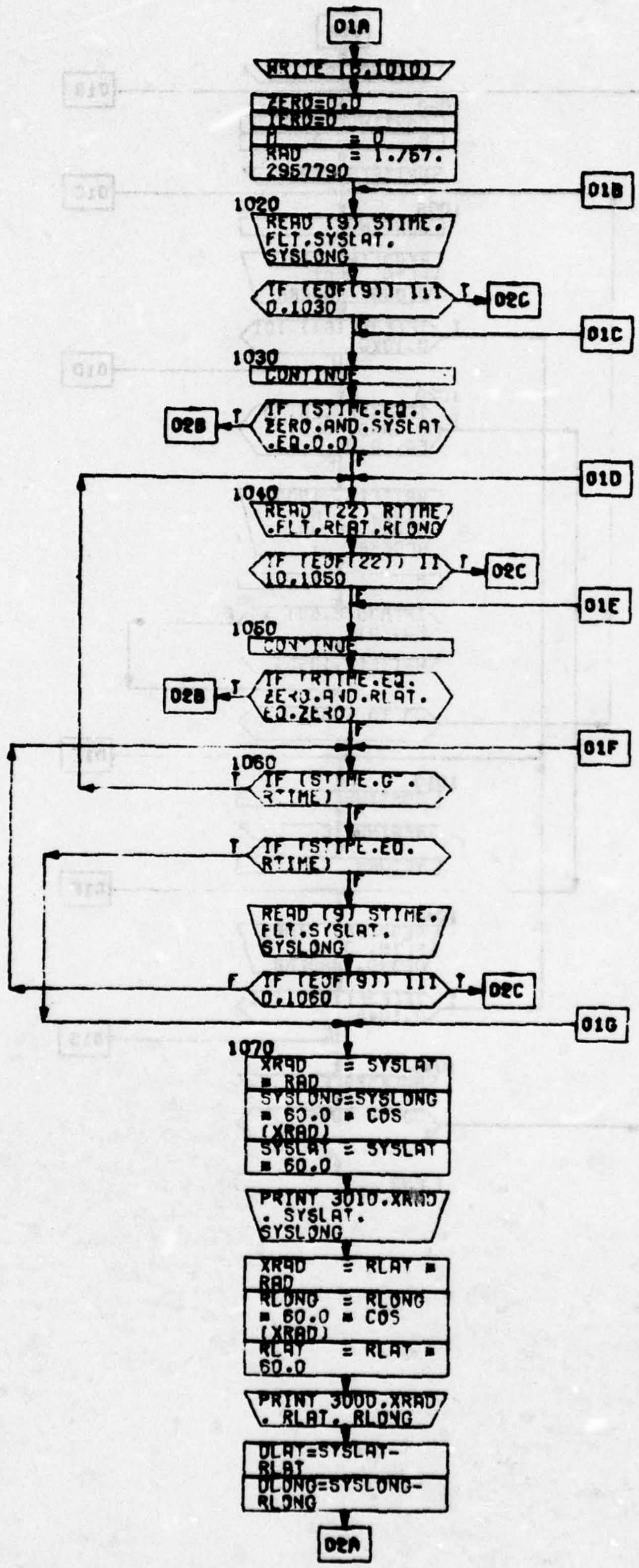


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE COMBNE

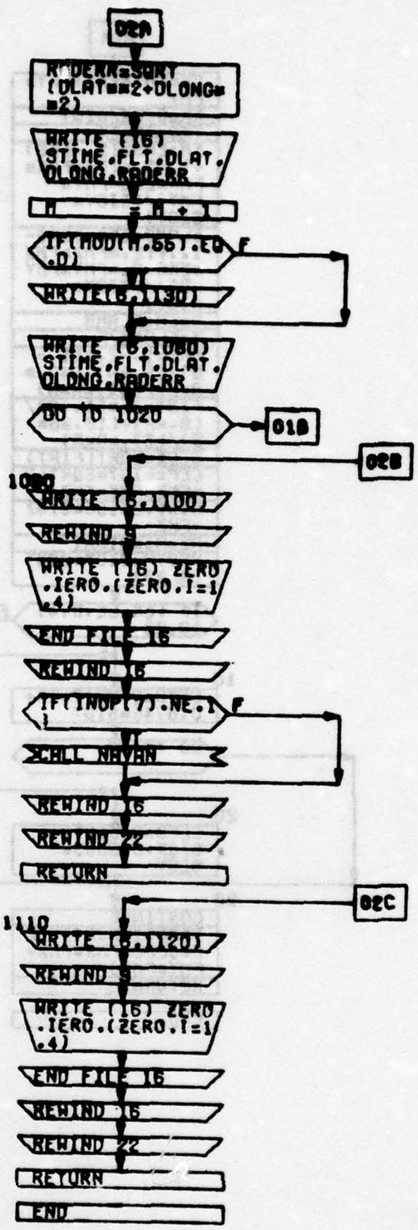


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE CALCEP

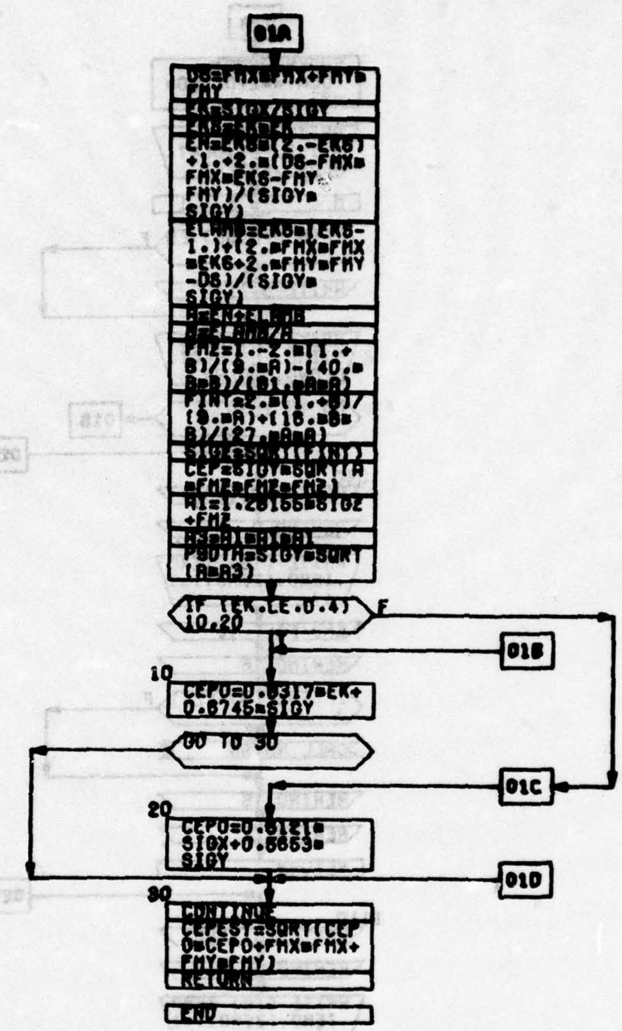


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE PERCET

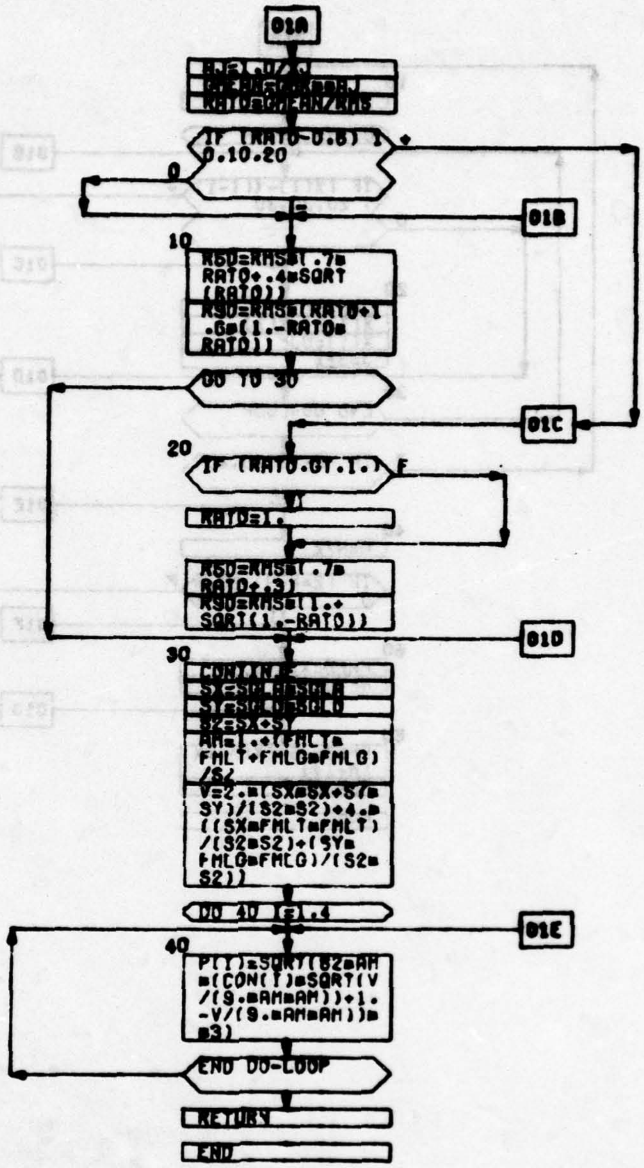


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE MEDIAN

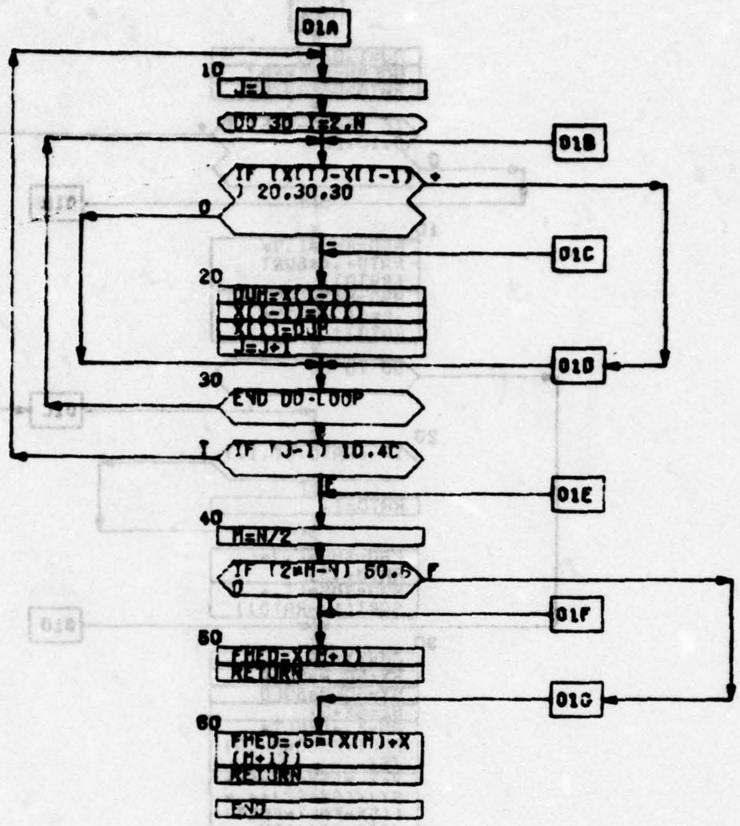


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE RCHK

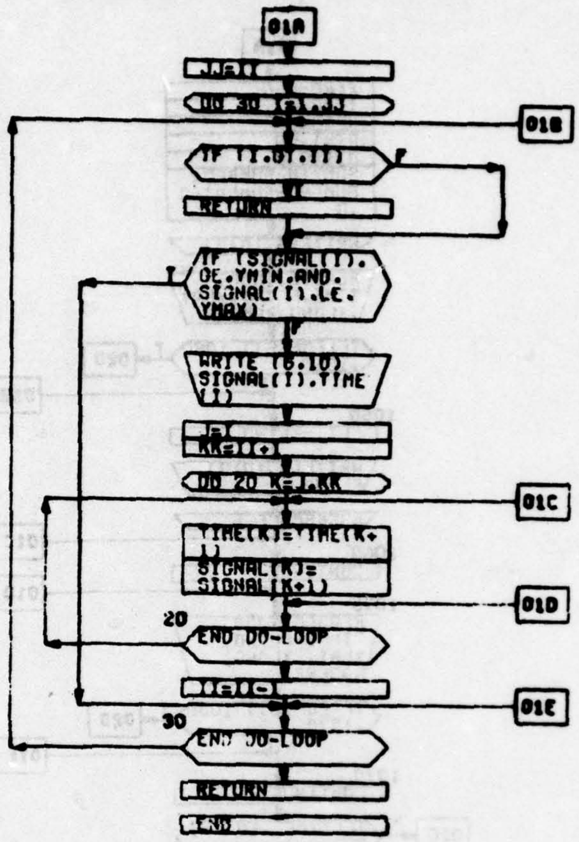


Figure A29   Program NAVAN Flowchart (continued)

SUBROUTINE RDCDS

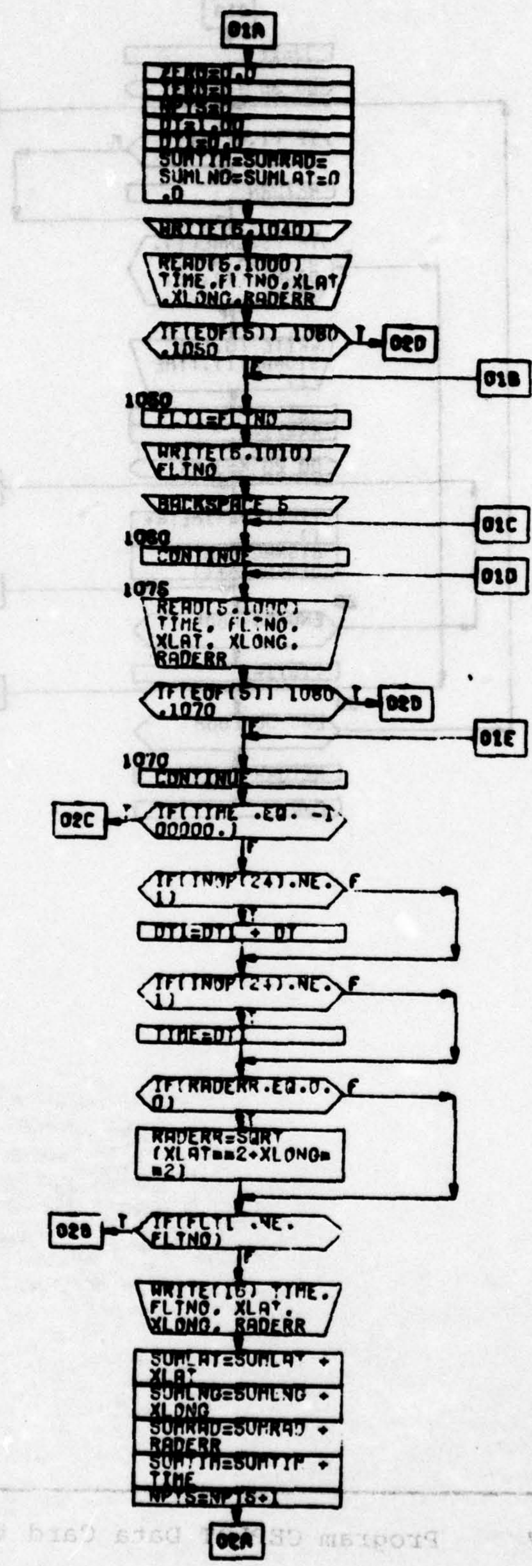


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE RDCOS

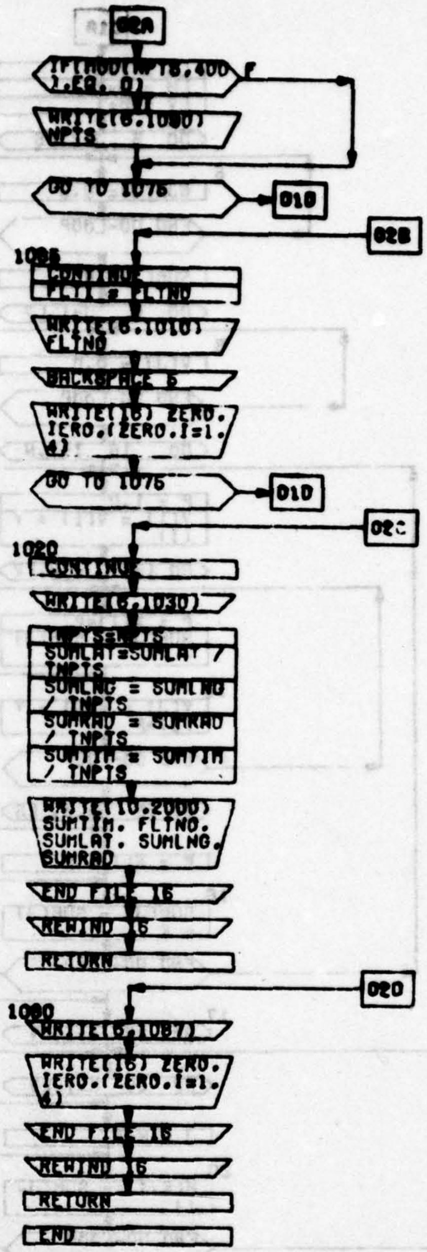


Figure A29   Program MAVAN Flowchart (continued)

SUBROUTINE LESSQ

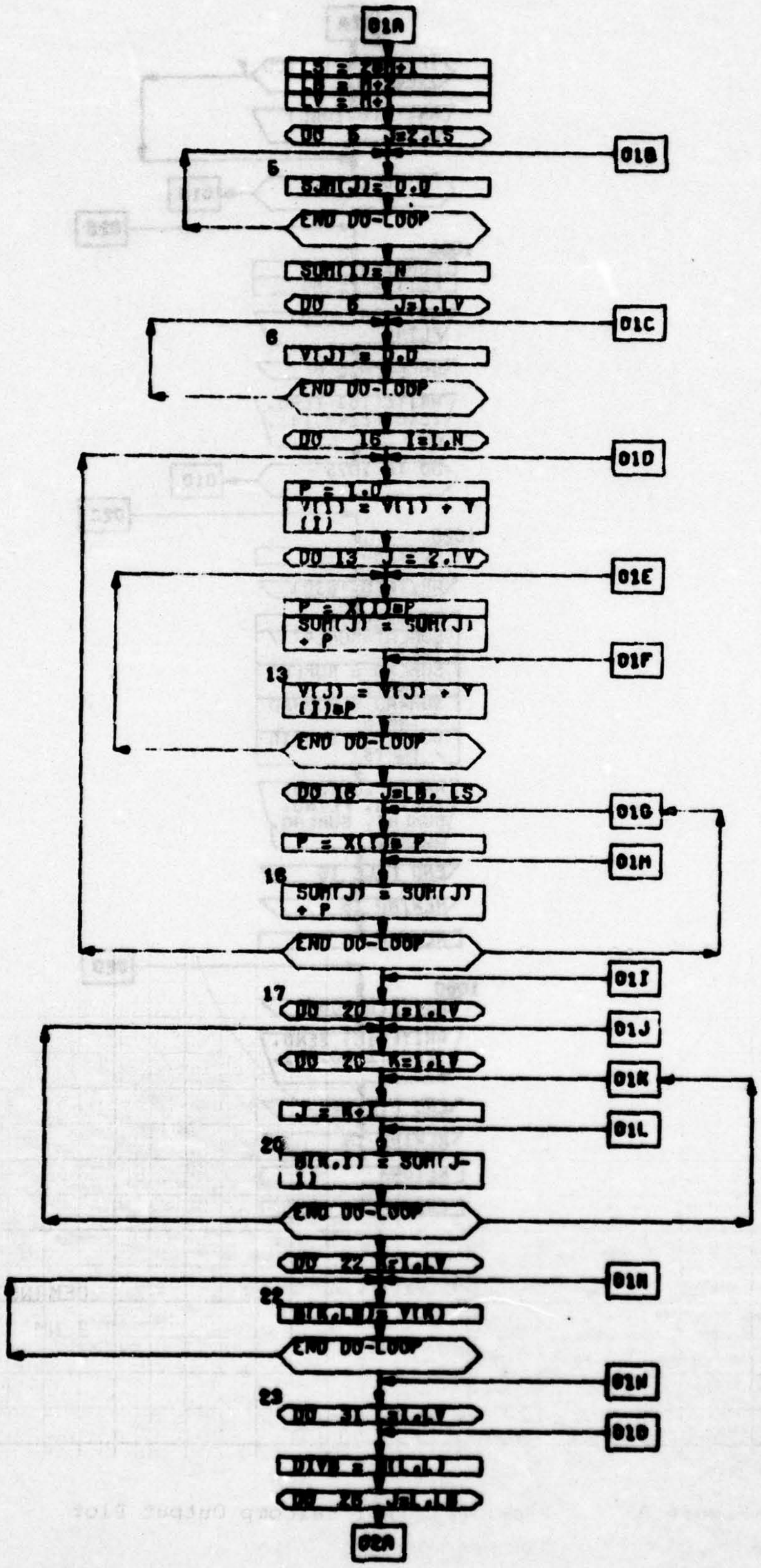


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE LESSQ

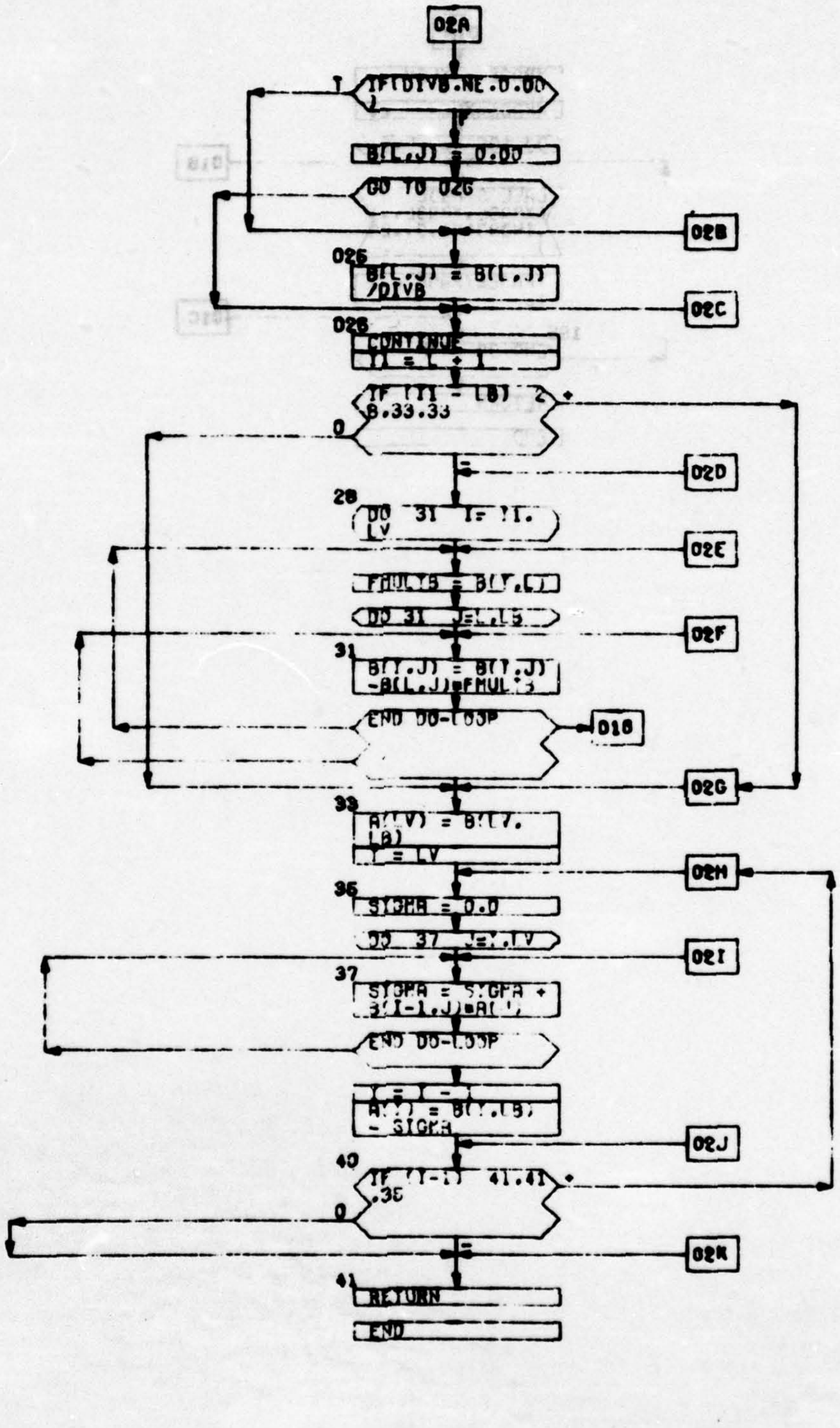


Figure A29 Program NAVAN Flowchart (continued)

SUBROUTINE COMMENT

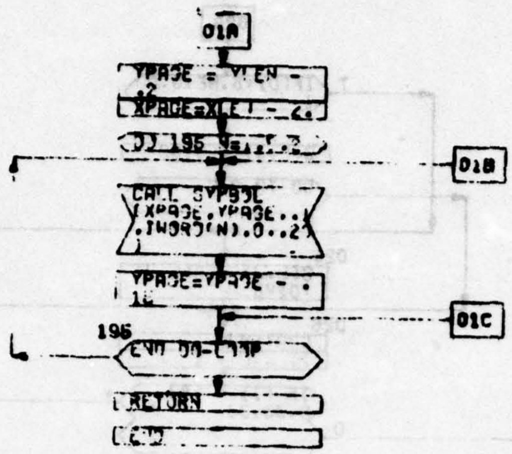


Figure A29 Program NAVAN Flowchart (concluded)

APPENDIX B

CEPLOT Computer Program

INTRODUCTION

The Circular Error of Probability Program (CEPLOT) calculates the CEP and plots the data. The input is navigation system end point position error data normalized to one hour, based on a linear error rate. Data are input in card form.

OVERVIEW

CEPLOT consists of the main program and subprograms. It reads the data, computes the error, normalizes the data, computes the CEP, and produces a tabular listing and Calcomp plot tape for plotting.

A flowchart is shown in figure B1.

The method used to calculate the CEP is the same as is used in NAVAN (Appendix A), which is based on the Air Standard 53/11.B, 15 August 1968, The Specification and Evaluation of the Accuracy of Inertial Navigation System.

PREPARATION FOR USE

The program deck of CEPLOT will be permanently stored at the AFFTC Systems Engineering Branch.

USER'S GUIDE

The deck developed for running CEPLOT is composed of three parts. The first part is the job control cards which are used to attach the Calcomp plot tapes and execute the program. Examples of these control cards are shown in figure B2.

The second portion of the program is the main program and subroutines.

The third portion of the program consists of two parts: (1) Tne parameter cards which control the program and plotting, and (2) The data cards. These data cards are shown in figure B3.

The output data from CEPLOT consists of a computer output listing, figure B4, and a Calcomp plot, figure B5.

INPUT CARDS FOR CEPLOT

CEPLOT data card #1, figure B6, contains the number of data points to be calculated and plotted, and the heading to be placed on the Calcomp plot.

CEPLOT data card #2, figure B7, contains the type of INS alignment, either gyrocompass (GC), best azimuth heading (BATH), or standard (STD), and the format of the input data. The data format may be "RAW" which means that the delta latitude, delta longitude, flight number, and time will be input. Radial error will be calculated and the data normalized. In the other format, the data are input as delta latitude, delta longitude, and radial error (PMT Left Blank).

CEPLOT data card #3, figure B8, the first data card, if not "RAW", will contain delta latitude, delta longitude, and radial error which has

been normalized. One card is used for each data point. If "RAW" data, the card, figure B9, will have flight number, delta latitude, delta longitude, and time in hours and minutes. This data will not have been normalized. One card is required for each data point.

FLOWCHART OF PROGRAM CEPLOT

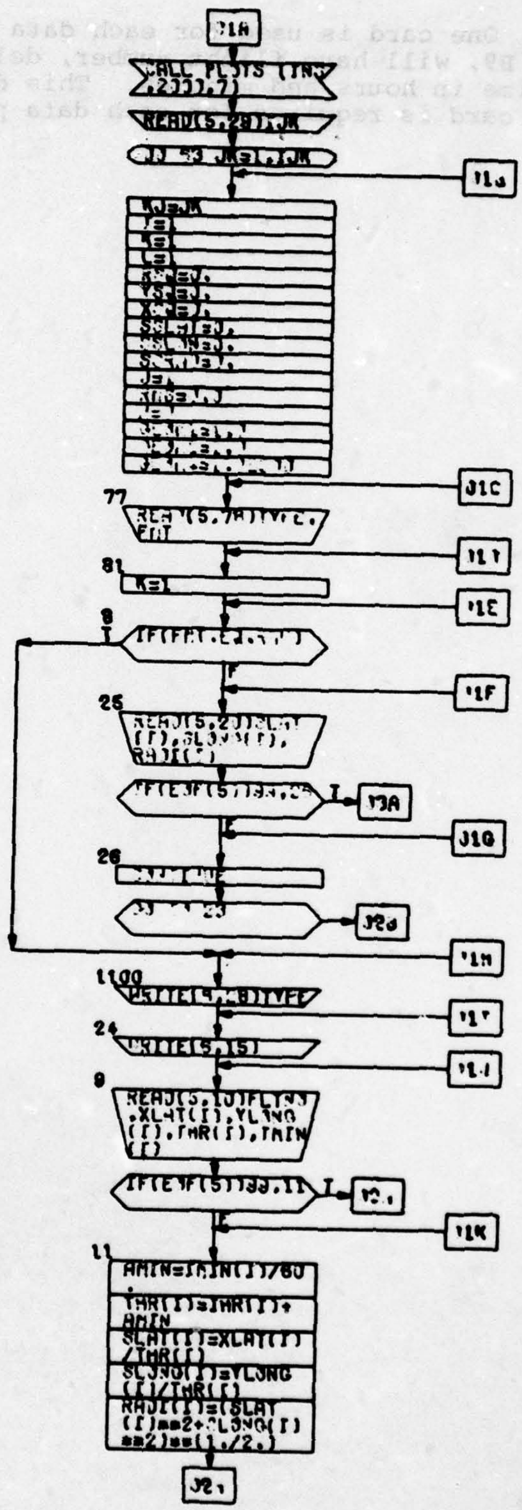


Figure B1 Program CEPLOT Flowchart

FLOWCHART OF PROGRAM CEPLOT

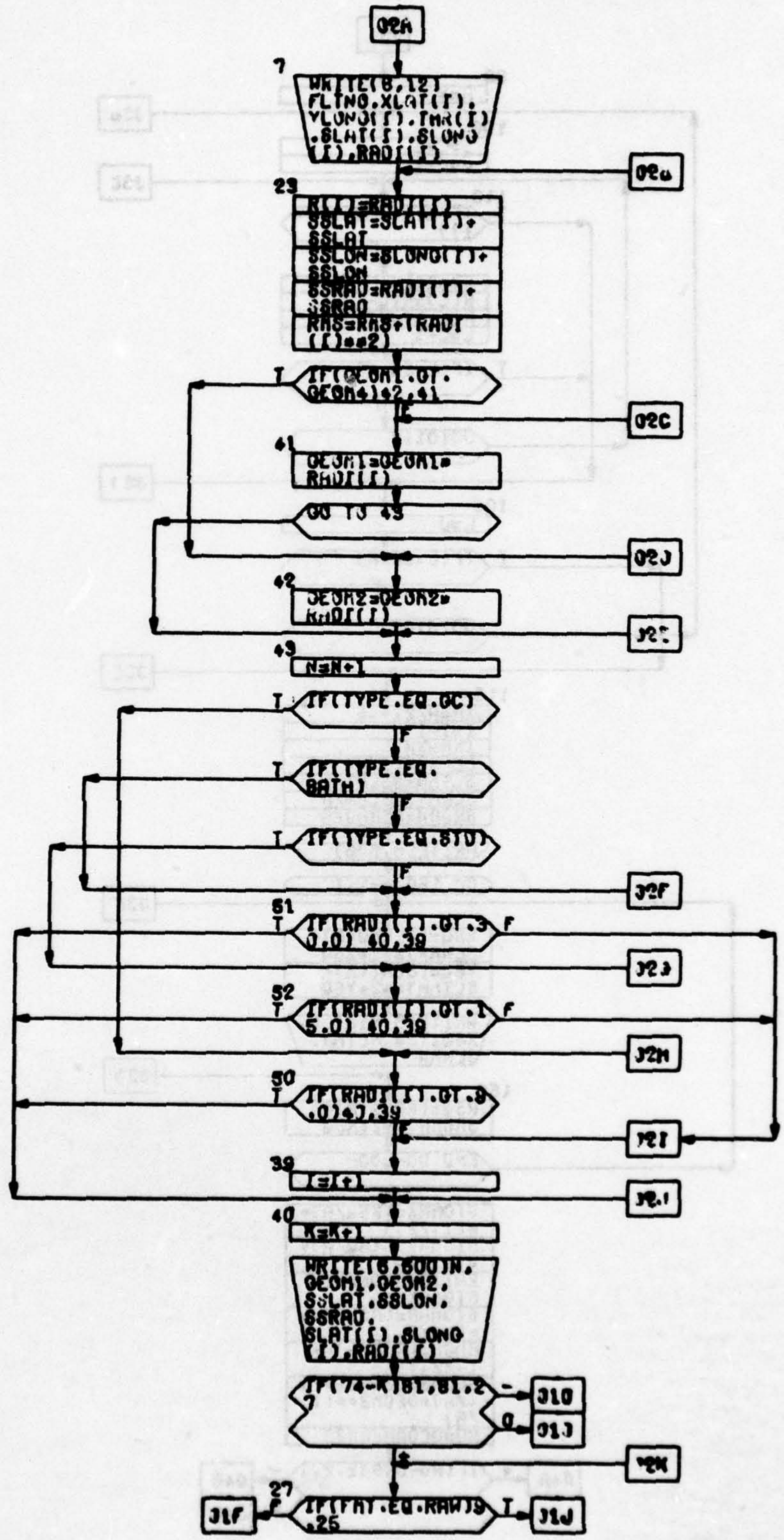


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF PROGRAM CEPLOT

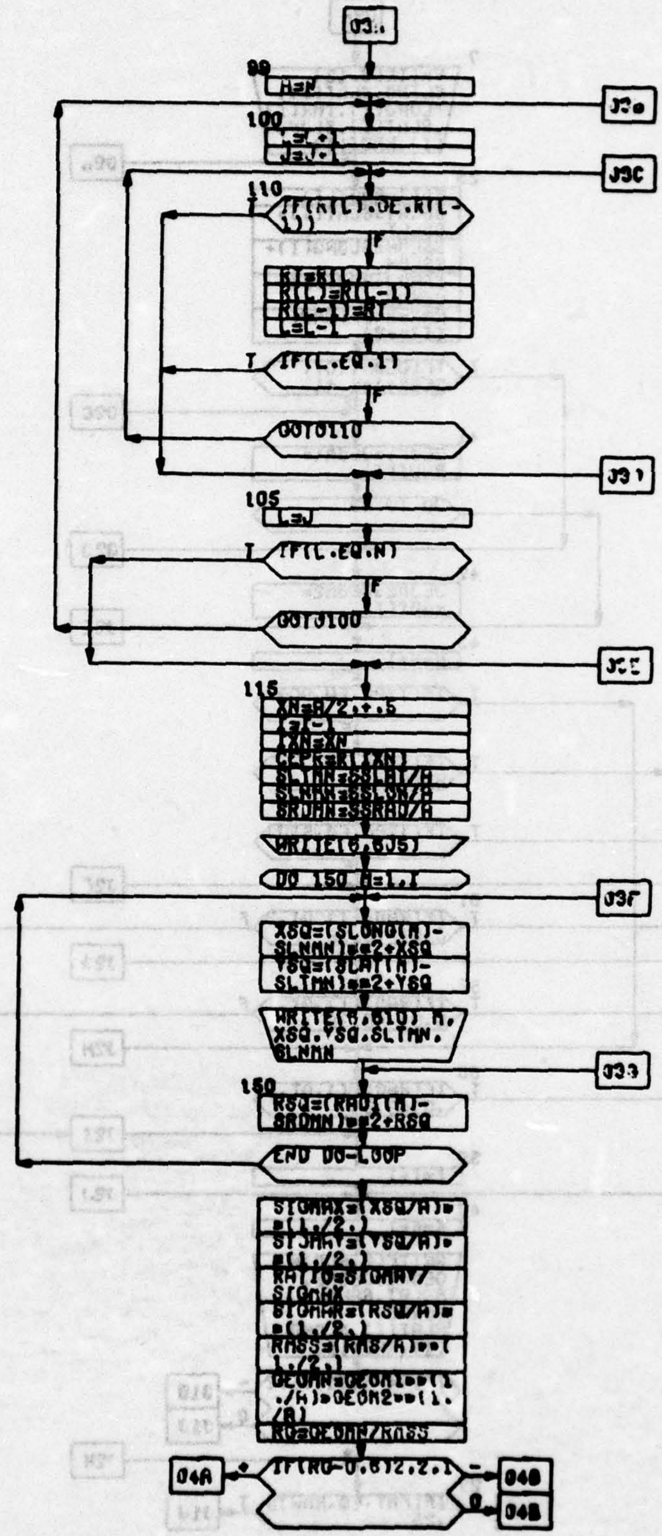


Figure B1 Program CEPLOT Flowchart (continued)

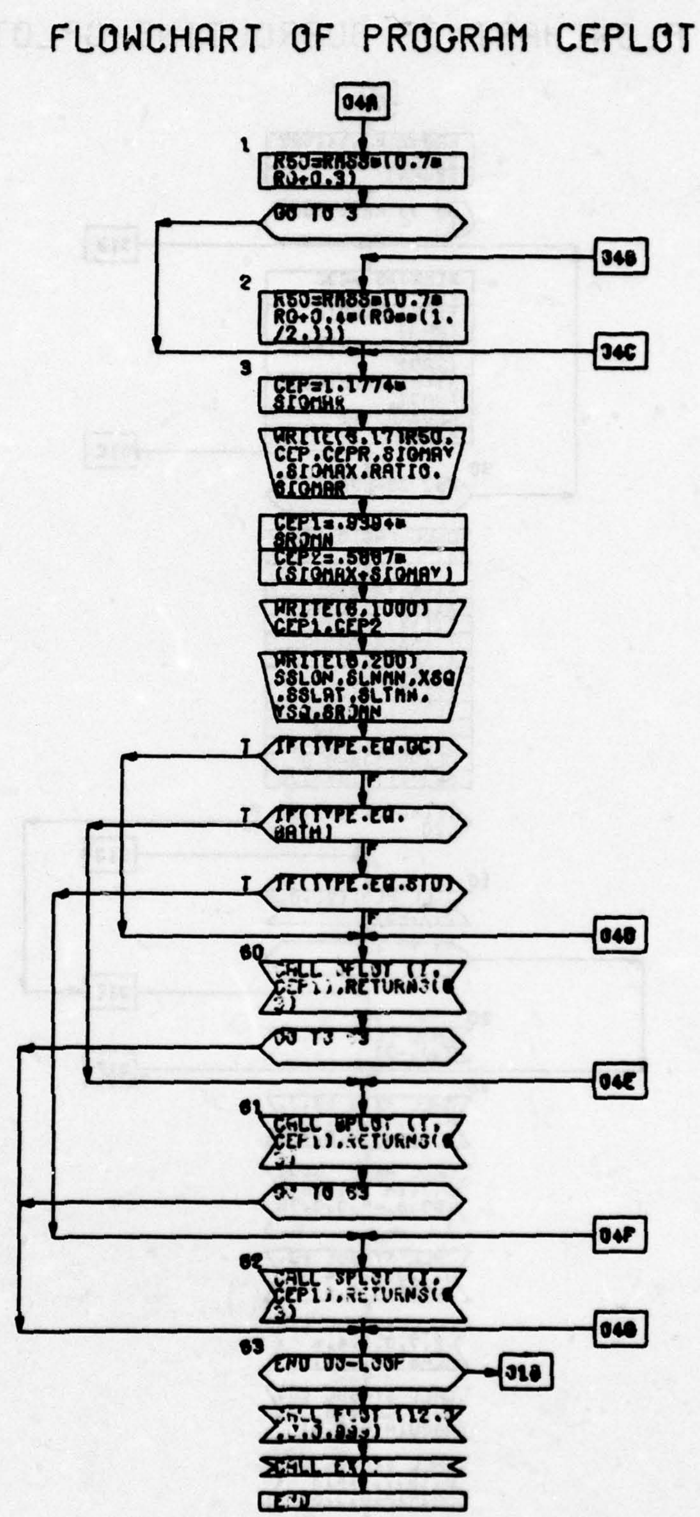


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE CPLOT

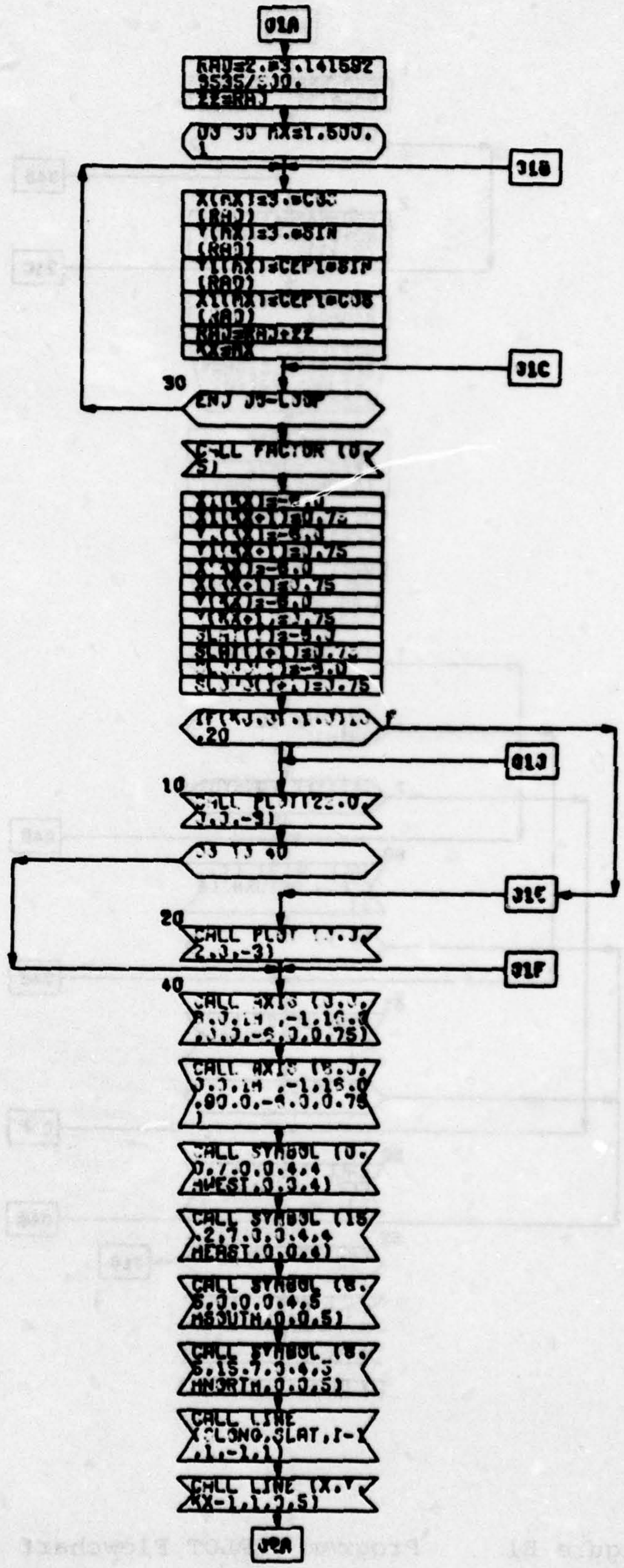


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE GPLOT

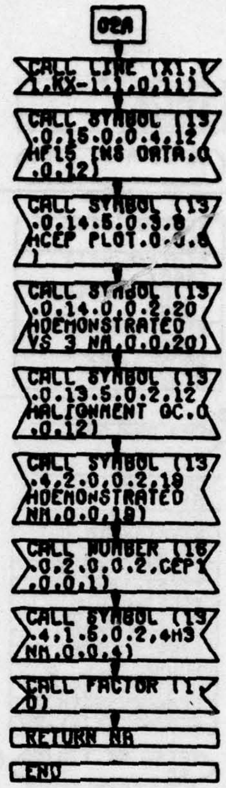


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE SPLOT

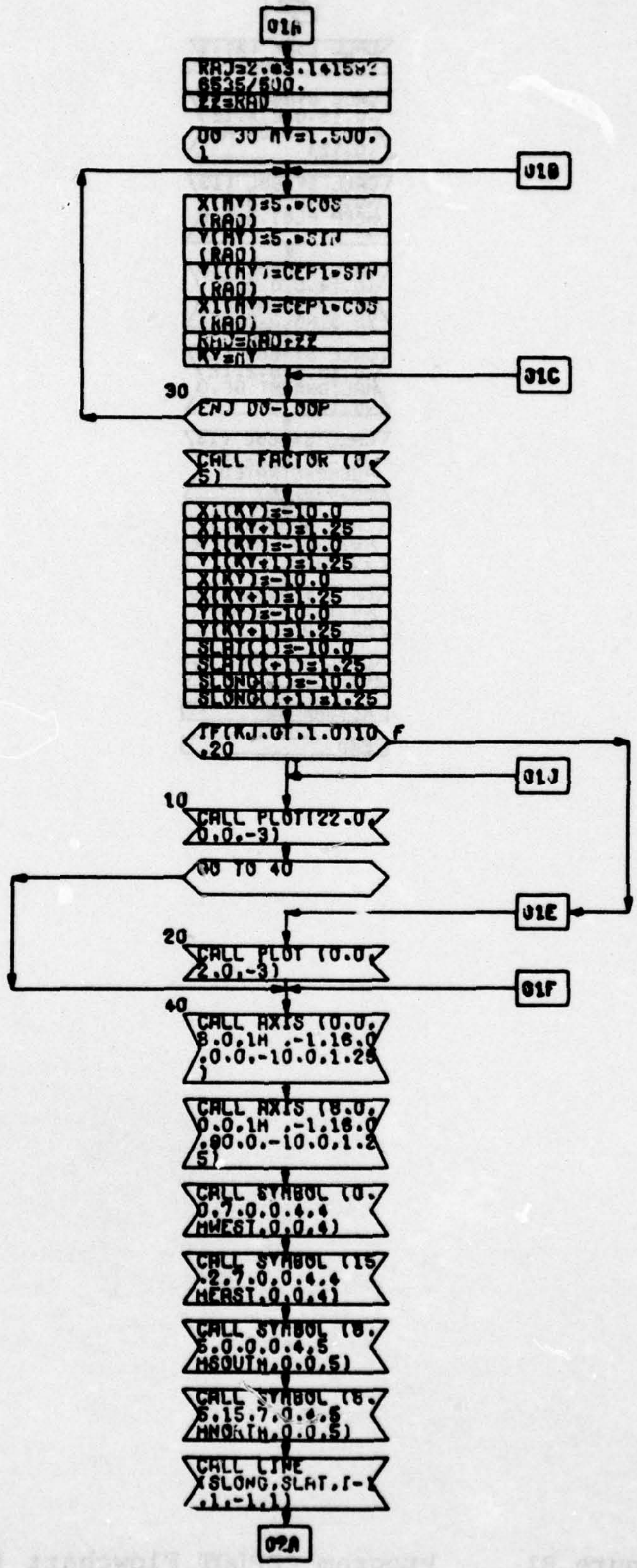


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE SPLOT

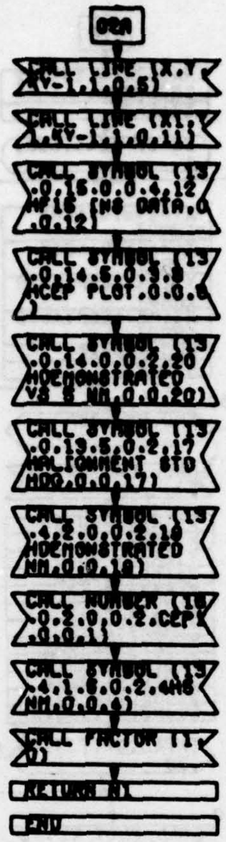


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE BPLOT

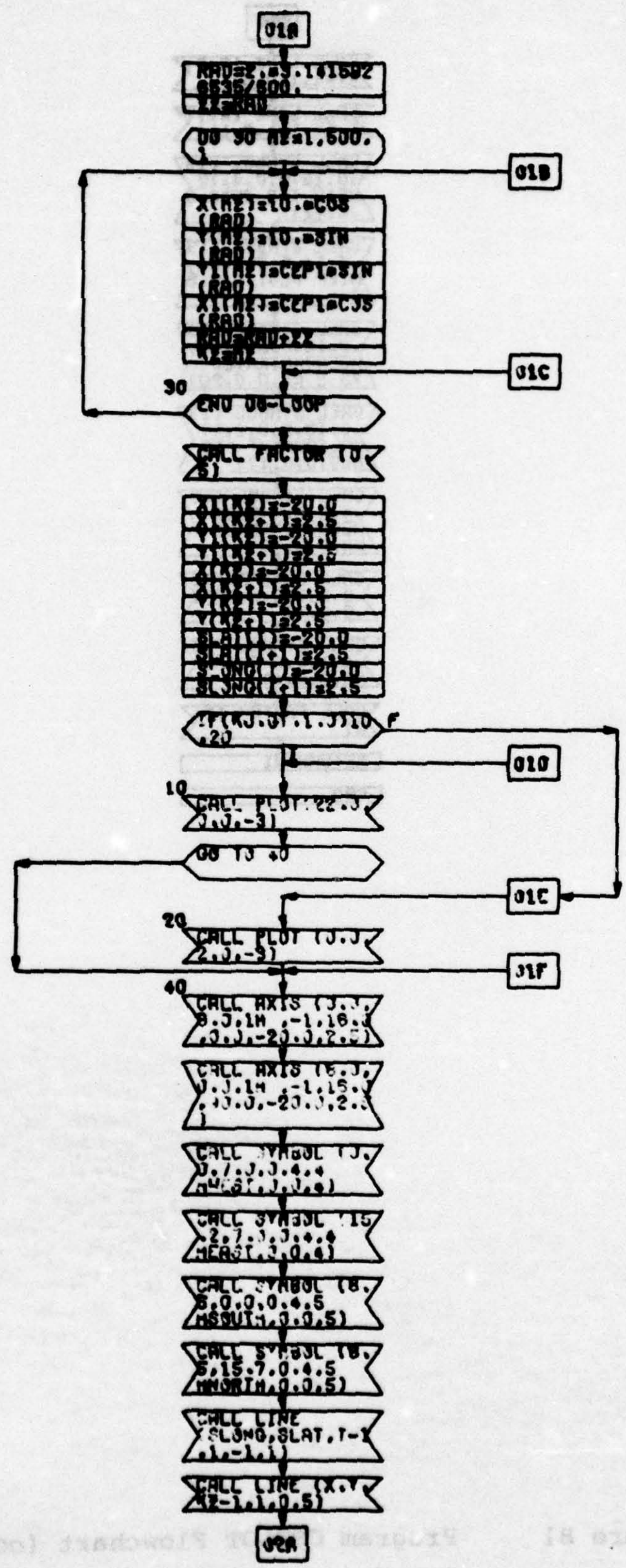


Figure B1 Program CEPLOT Flowchart (continued)

FLOWCHART OF SUBROUTINE BPLOT

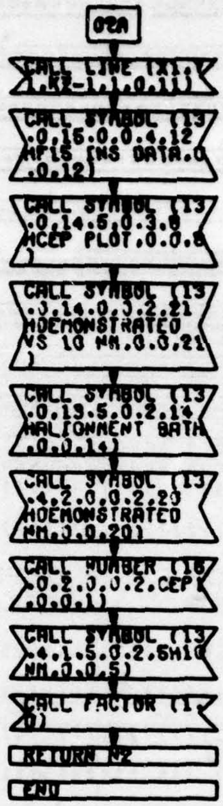


Figure B1 Program CEPLOT Flowchart (concluded)

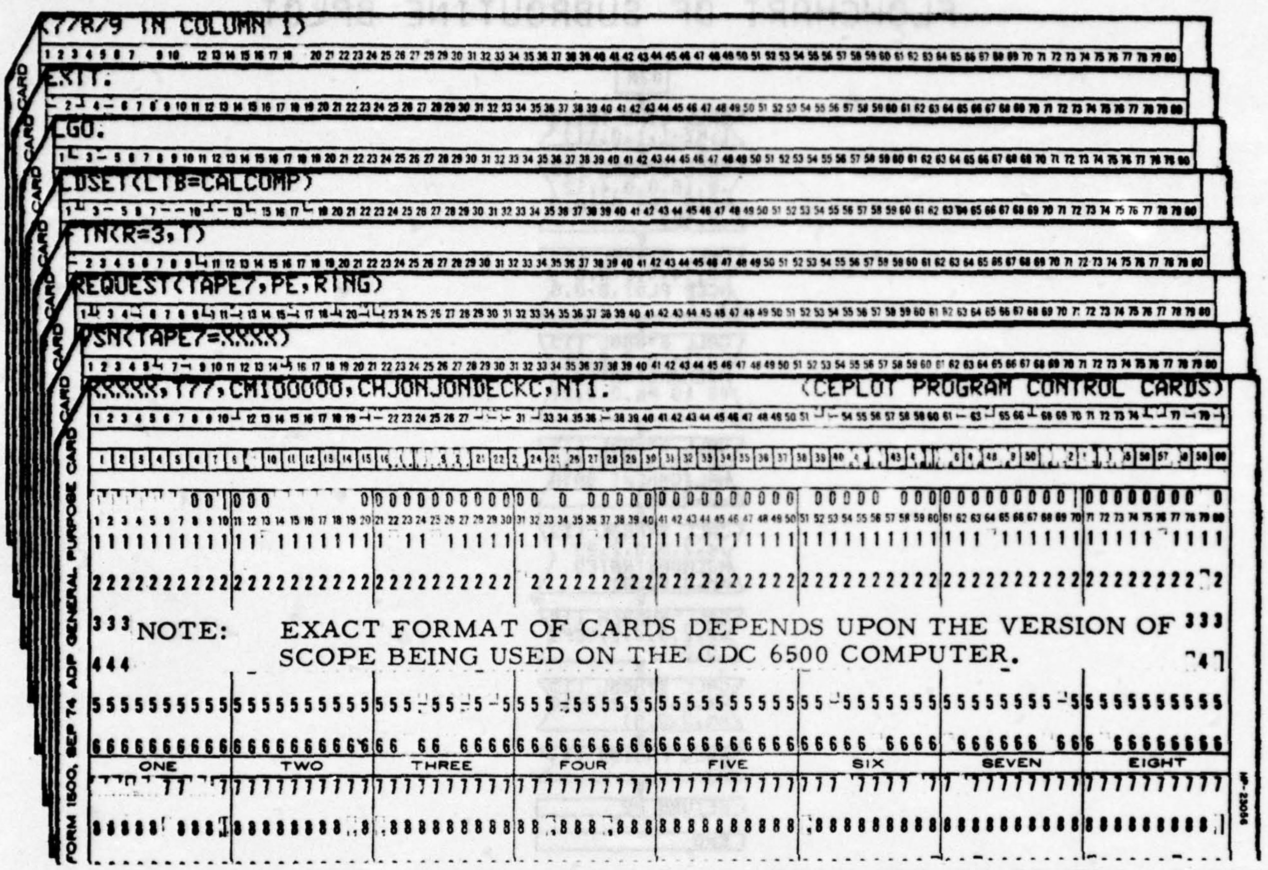


FIGURE B2 SAMPLE DECK SETUP OF PROGRAM CEPLOT CONTROL CARDS.

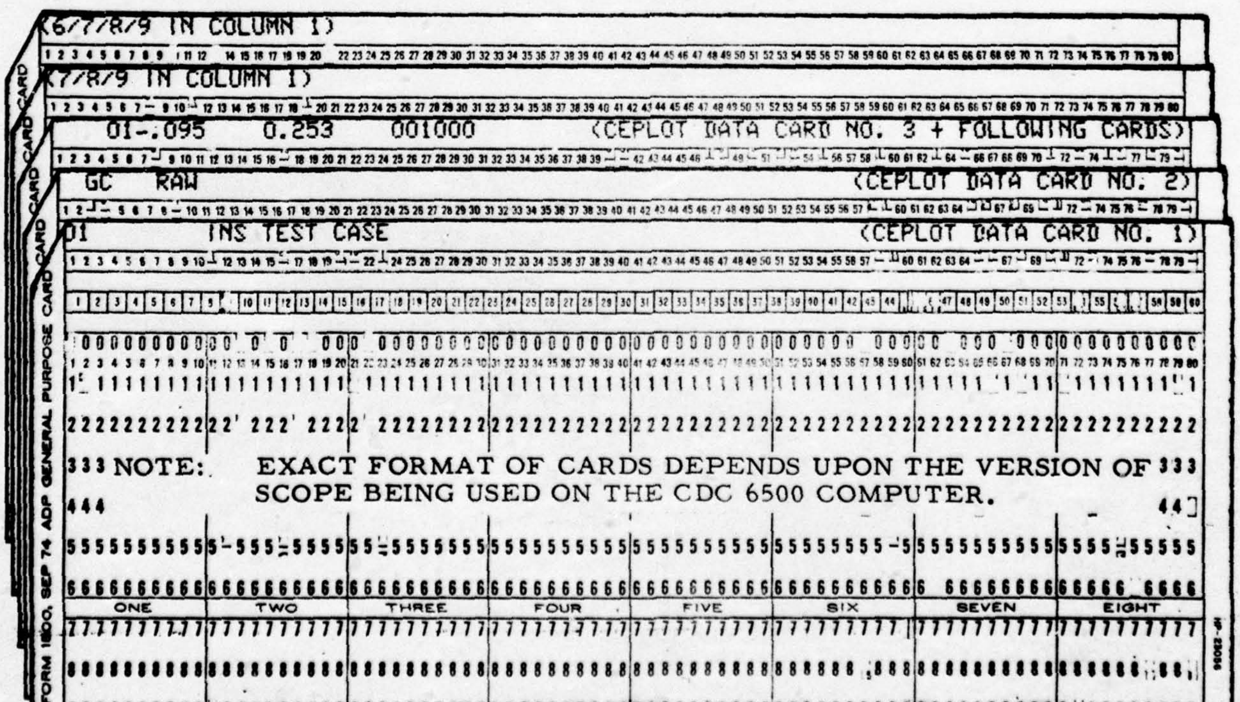


FIGURE B3 SAMPLE DECK SETUP OF PROGRAM CEPLOT DATA CARDS.

TERMINAL DATA FOR A   GC ALIGNMENT

FLT NO		TERMINAL DELTA LAT (NM)	TERMINAL DELTA LONG (NM)	ELAPSED TIME (HR)		NORMALIZED DELTA LAT (NM)		NORMALIZED DELTA LONG (NM)		NORMALIZED RADIAL (NM)
01		-.095	.253	1.000		-.095		.253		.270
	1	.27025E+00	.10000E+01	-.095	.253	.270	0.000	0.000	0.000	
01		2.555	1.066	1.000		2.555		1.066		2.776
	2	.75027E+00	.10000E+01	2.460	1.339	3.046	0.000	0.000	0.000	
01		-.951	-1.430	1.000		-.951		-1.430		1.717
	3	.12885E+01	.10000E+01	1.509	-.091	4.764	0.000	0.000	0.000	
01		1.399	.225	1.000		1.399		.225		1.417
	4	.18257E+01	.10000E+01	2.908	.134	6.181	0.000	0.000	0.000	
01		1.020	-1.261	1.000		1.020		-1.261		1.637
	5	.29896E+01	.10000E+01	3.925	-1.147	7.818	0.000	0.000	0.000	
01		1.324	.111	1.000		1.324		.111		1.329
	6	.39722E+01	.10000E+01	5.252	-1.036	9.147	0.000	0.000	0.000	
01		1.497	.542	1.000		1.497		.542		1.592
	7	.63241E+01	.10000E+01	6.749	-.494	10.739	0.000	0.000	0.000	
01		-.168	-.238	1.000		-.168		-.238		.291
	8	.16423E+01	.10000E+01	6.581	-.732	11.030	0.000	0.000	0.000	
01		1.008	.687	1.000		1.008		.687		1.220
	9	.22474E+01	.10000E+01	7.589	-.045	12.250	0.000	0.000	0.000	
01		-1.213	.753	1.000		-1.213		.753		1.428
	10	.32086E+01	.10000E+01	6.376	.708	13.678	0.000	0.000	0.000	
01		-.152	-.574	1.000		-.152		-.574		.594
	11	.19032E+01	.10000E+01	6.224	.134	14.272	0.000	0.000	0.000	
01		1.100	1.259	1.000		1.100		1.259		1.672
	12	.31852E+01	.10000E+01	7.324	1.393	15.944	0.000	0.000	0.000	
01		.575	-.591	1.000		.575		-.591		.825
	13	.26264E+01	.10000E+01	7.899	.802	16.768	0.000	0.000	0.000	
01		-.751	-.460	1.000		-.751		-.460		.881
	14	.23409E+01	.10000E+01	7.148	.322	17.659	0.000	0.000	0.000	
01		-.806	-1.226	1.000		-.806		-1.226		1.467
	15	.35346E+01	.10000E+01	6.342	-.904	19.127	0.000	0.000	0.000	
01		-.324	-.534	1.000		-.324		-.534		.625
	16	.21453E+01	.10000E+01	6.018	-1.438	19.751	0.000	0.000	0.000	
01		.439	-.689	1.000		.439		-.689		.817
	17	.17526E+01	.10000E+01	6.457	-2.127	20.568	0.000	0.000	0.000	
01		.143	[illegible]	1.000		.143		[illegible]		[illegible]
	18	.17358E+01	.10000E+01	6.600	-3.107	21.559	0.000	0.000	0.000	
01		-.717	.760	1.000		-.717		.760		1.045
	19	.18136E+01	.10000E+01	5.883	-2.347	22.603	0.000	0.000	0.000	
01		-1.955	-.258	1.000		-1.955		-.258		1.972
	20	.35763E+01	.10000E+01	3.928	-2.605	24.575	0.000	0.000	0.000	
01		-.586	1.261	1.000		-.586		1.261		1.391
	21	.49729E+01	.10000E+01	3.342	-1.344	25.966	0.000	0.000	0.000	
01		1.650	-.474	1.000		1.650		-.474		1.717
	22	.85372E+01	.10000E+01	4.992	-1.818	27.663	0.000	0.000	0.000	
01		1.015	-.019	1.000		1.015		-.019		1.015
	23	[illegible]	.10000E+01	6.007	-1.837	28.678	0.000	0.000	0.000	
01		-1.337	1.700	1.000		-1.337		1.700		2.163
	24	.15744E+02	.10000E+01	4.670	-.137	30.861	0.000	0.000	0.000	
01		.190	1.400	1.000		.190		1.400		1.413
	25	.26483E+02	.10000E+01	4.860	1.263	32.273	0.000	0.000	0.000	
01		-.821	-.711	1.000		-.821		-.711		1.086
	26	.28762E+02	.10000E+01	4.039	.552	33.359	0.000	0.000	0.000	
01		.580	.249	1.000		.580		.249		.631
	27	.31594E+02	.10000E+01	4.619	.801	[illegible]	0.000	0.000	0.000	
01		-.936	-.851	1.000		-.936		-.851		1.265
	28	.22966E+02	.10000E+01	3.683	-.050	35.256	0.000	0.000	0.000	
01		-1.316	.217	1.000		-1.316		.217		1.334
	29	.33631E+02	.10000E+01	2.367	.167	36.589	0.000	0.000	0.000	
01		-1.019	1.000	1.000		-1.019		1.000		1.434
	30	.43926E+02	.10000E+01	1.348	1.176	38.023	0.000	0.000	0.000	

1	[illegible]	[illegible]	.045	.039
2	[illegible]	6.320	.045	.039
3	[illegible]	[illegible]	.045	.039
4	[illegible]	[illegible]	.045	.039
5	[illegible]	[illegible]	.045	.039
6	[illegible]	[illegible]	.045	.039
7	[illegible]	[illegible]	.045	.039
8	[illegible]	[illegible]	.045	.039
9	[illegible]	[illegible]	.045	.039
10	[illegible]	[illegible]	.045	.039
11	[illegible]	[illegible]	.045	.039
12	[illegible]	[illegible]	.045	.039
13	[illegible]	[illegible]	.045	.039
14	[illegible]	[illegible]	.045	.039
15	[illegible]	[illegible]	.045	.039
16	[illegible]	[illegible]	.045	.039
17	[illegible]	[illegible]	.045	.039
18	[illegible]	[illegible]	.045	.039
19	[illegible]	[illegible]	.045	.039
20	[illegible]	[illegible]	.045	.039
21	[illegible]	[illegible]	.045	.039
22	[illegible]	[illegible]	.045	.039
23	[illegible]	[illegible]	.045	.039
24	[illegible]	[illegible]	.045	.039
25	[illegible]	[illegible]	.045	.039
26	[illegible]	[illegible]	.045	.039
27	[illegible]	[illegible]	.045	.039
28	[illegible]	[illegible]	.045	.039
29	[illegible]	[illegible]	.045	.039
30	21.719	34.896	.045	.039

RSQ= 1.207   CEP= .020   CEPR= 1.329   S Y= 1.079   S X= .051   SY/SX= 1.260   GRAD= .399

CEP1= 1.391   CEP2= 1.136

SUM X= 1.176   X MEAN= .039   SUM X SQ= 21.719

SUM Y= 1.348   Y MEAN= .045   SUM Y SQ= 34.896

MEAN RADIAL= 1.267

Figure B4   Program CEPLOT Computer Output Listing

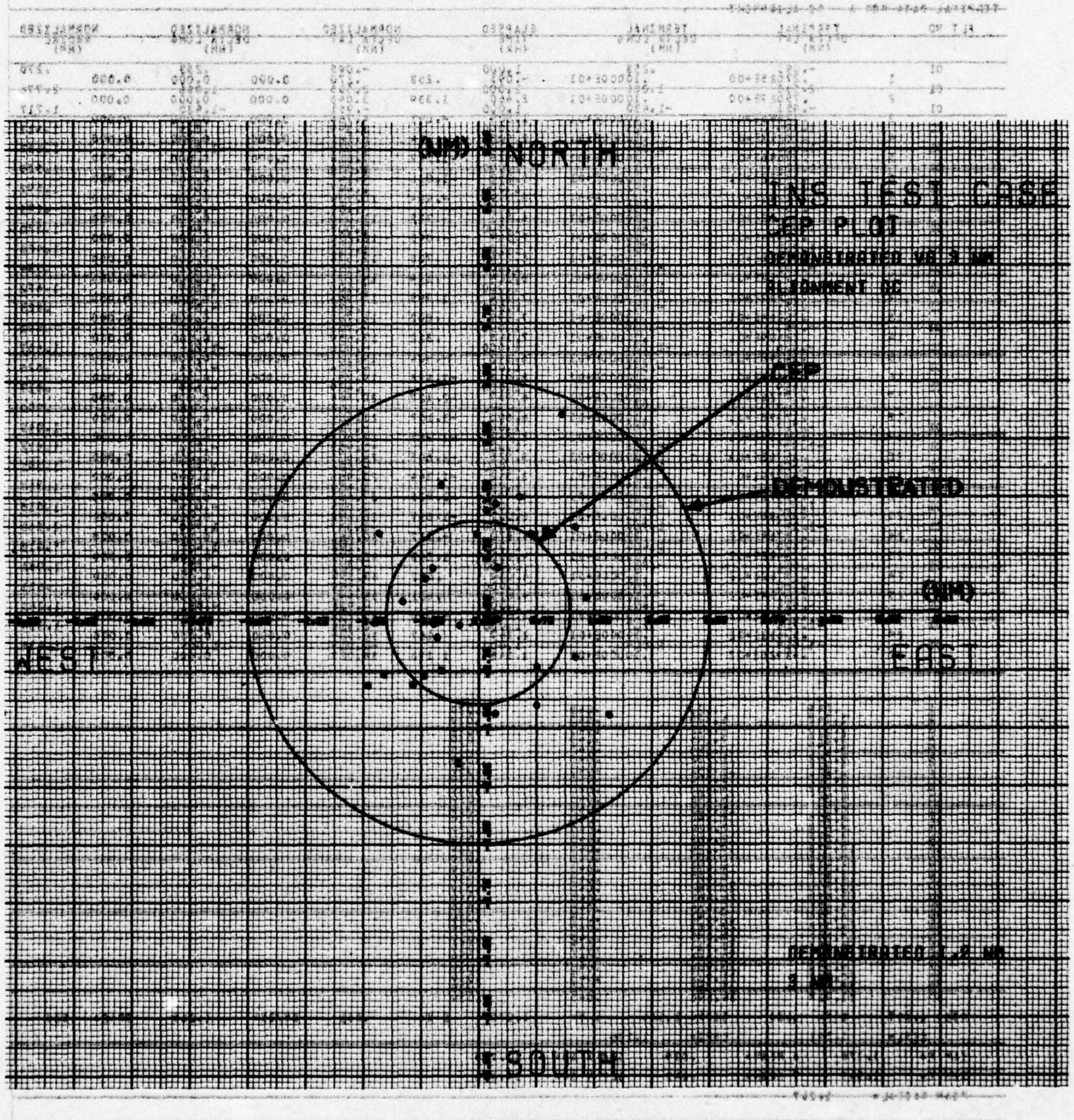


Figure B5 Program CEPLOT Calcomp Output Plot

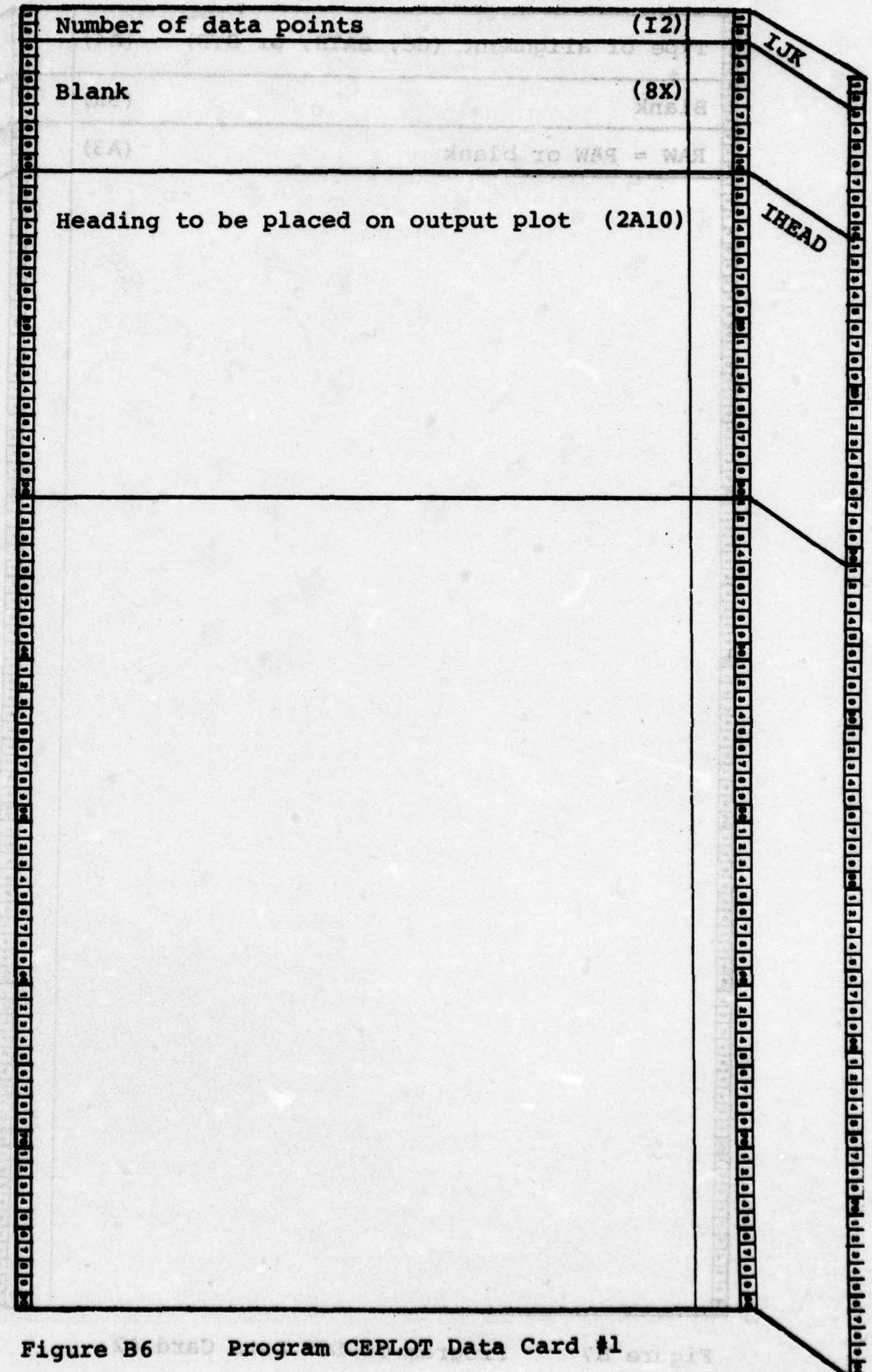


Figure B6 Program CEPLOT Data Card #1

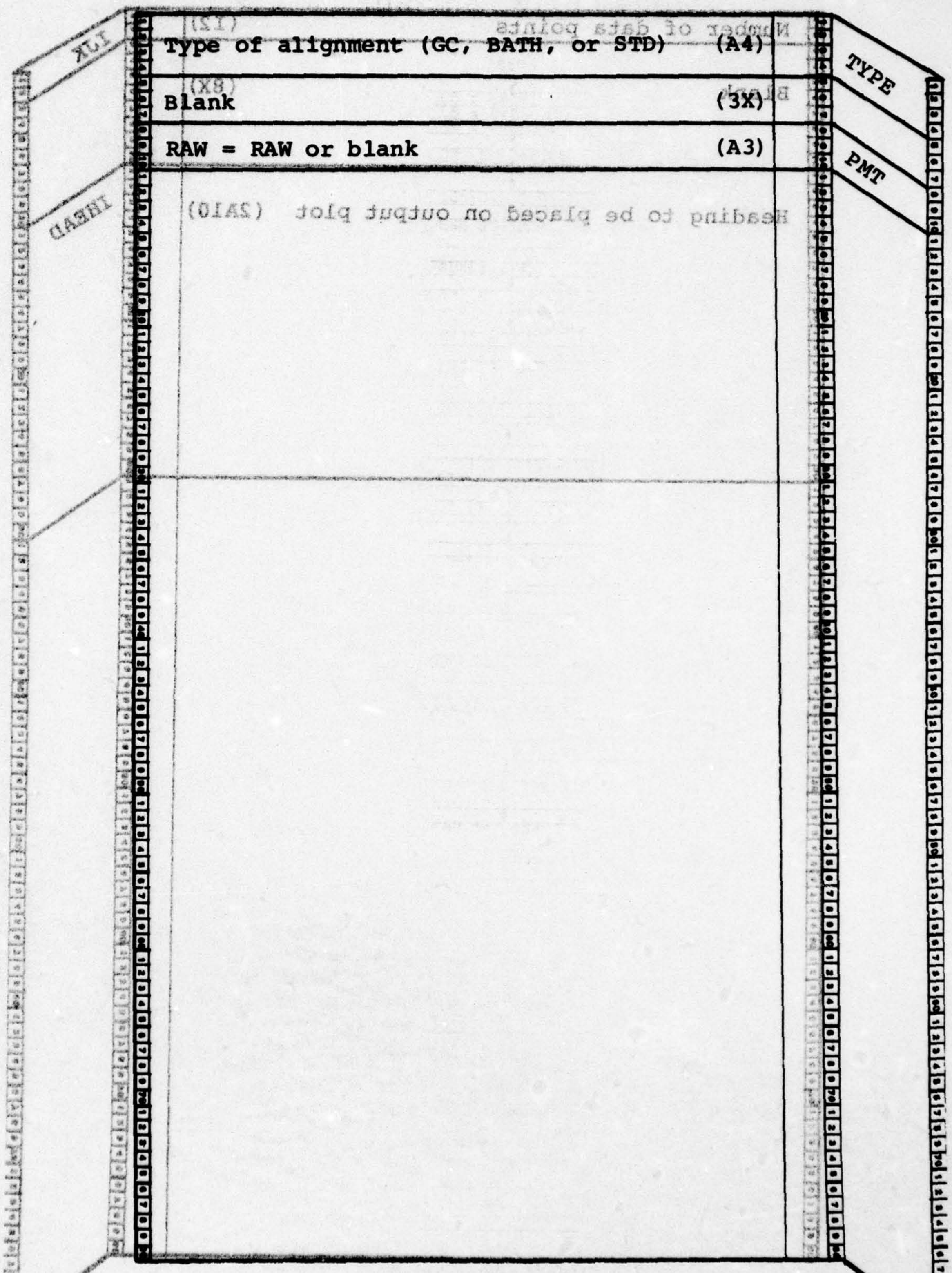


Figure B7 Program CEPLOT Data Card #2

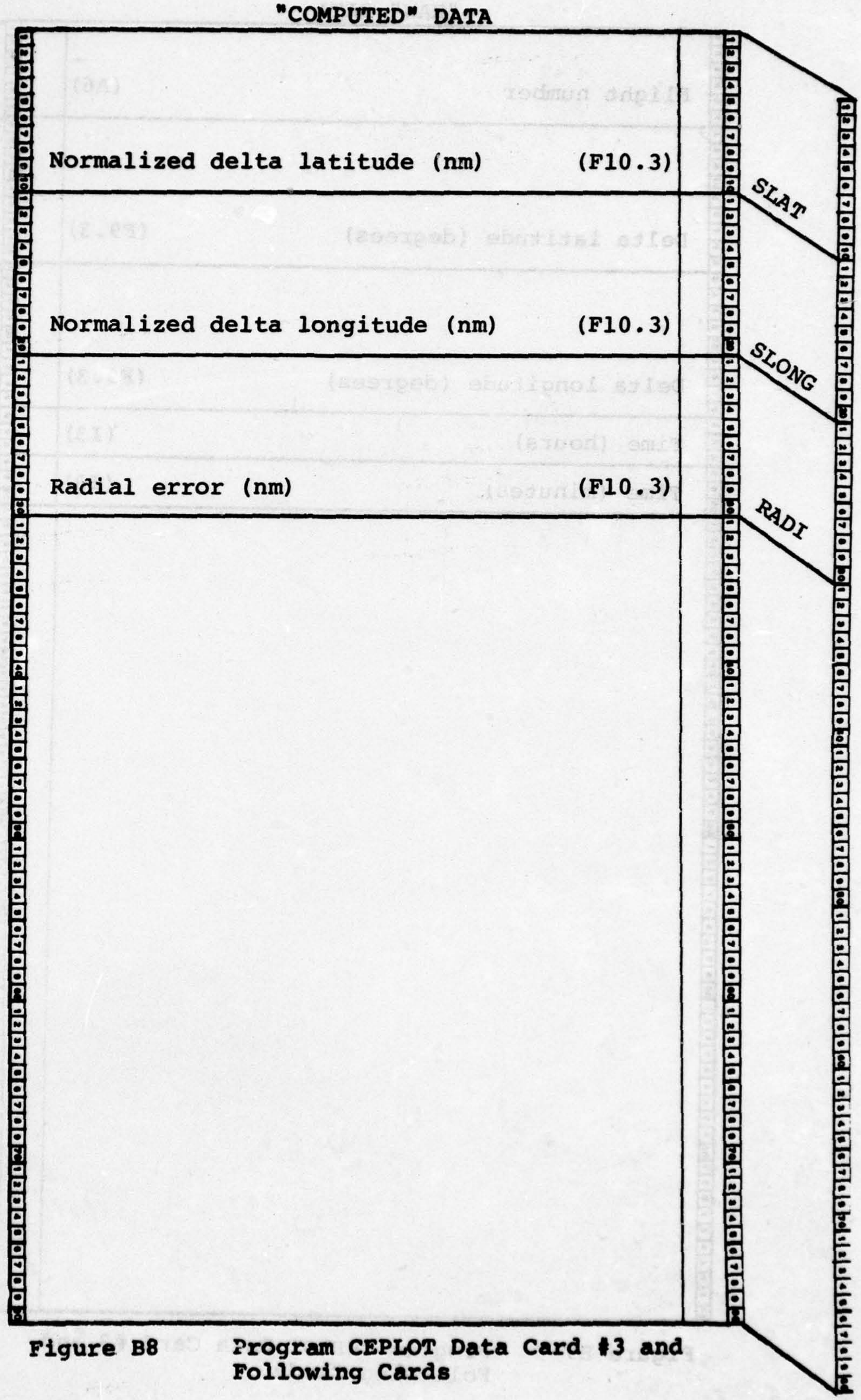


Figure B8 Program CEPLOT Data Card #3 and Following Cards

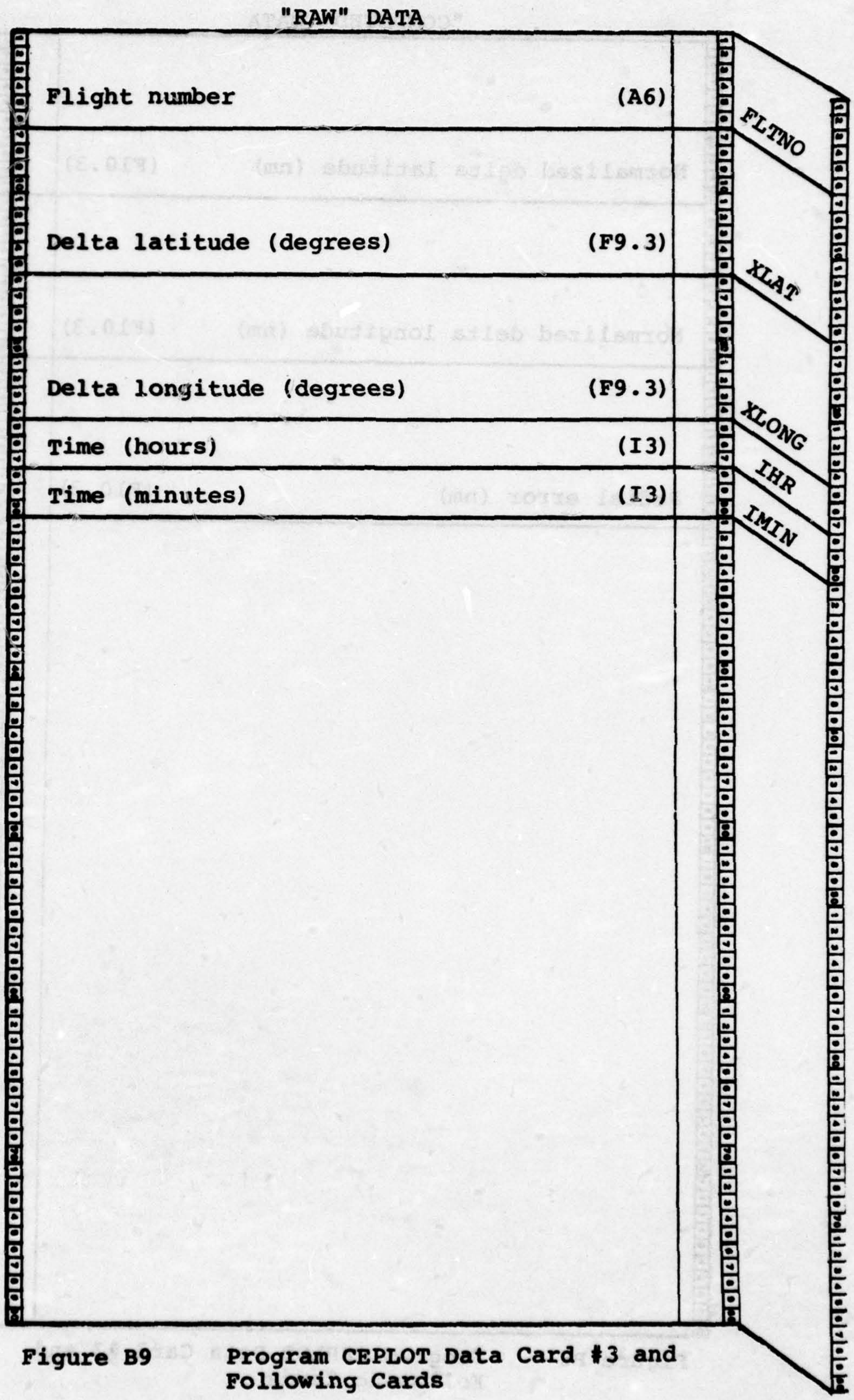


Figure B9 Program CEPLOT Data Card #3 and Following Cards

APPENDIX C

Check Cases

The following check case for program NAVAN uses data from an onboard navigation system and space positioning (RADAR) tracking data. The ADAS and RADAR data are first merged and placed on the New History Flight File, then another set of data is added to this file and the merged data is analyzed and the results are plotted. All intermediate data was printed for help in diagnosis of program errors.

$DATA NAVAN INPUT OPTIONS

```
INOP   = 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
MODO   = .9E+73,
[illegible] = 0,
FLTN   = 0,
NX     = 0,
$END
```

CALL ADAS SYSTEM DATA, PLUS RADAR(CALL ADASRAD) [illegible]

ENTERING READ ADAS TAPE? ADAS SYSTEM DATA

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NAVIGATION SYSTEM DATA AFTER CALCULATIONS

DATA TAPE 8

ELAPSED TIME(SEC)	FLIGHT NUMBER	LAT (DEG)	LONG (DEG)
[illegible]	[illegible]	[illegible]	[illegible]

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT

DATA TAPE 4

ELAPSED TIME(SEC)	FLIGHT NUMBER	LAT (DEG)	LONG (DEG)
59.7790	210	34.8514	117.8490

DATA TAPE 8

ELAPSED TIME(SEC)	FLIGHT NUMBER	LAT (DEG)	LONG (DEG)
60.7790	210	[illegible]	117.8490
[illegible]	[illegible]	[illegible]	[illegible]
114.7790	210	34.8637	117.7100

*************END OF ALL SYSTEM DATA*************

RADAR DATA

ENTER RADAR READ TAPE?

[illegible]	[illegible]	[illegible]	[illegible]

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT

SMOOTHED RADAR DATA

SMOOTH DATA TAPE22

ELAPSED TIME(SEC)	VELOCITY FT/SEC	LAT (DEG)	LONG (DEG)
.7790	628.686	34.880	117.923
[illegible]	[illegible]	[illegible]	[illegible]
2.7790	619.126	34.877	117.925
3.7790	624.373	34.876	117.926
4.7790	592.726	34.875	117.927
5.7790	625.673	34.873	117.928
[illegible]	[illegible]	[illegible]	[illegible]
13.7790	703.529	34.859	117.930
[illegible]	[illegible]	[illegible]	[illegible]
50.7790	761.973	34.840	117.858
[illegible]	[illegible]	[illegible]	[illegible]
53.7790	742.264	34.843	117.851
[illegible]	[illegible]	[illegible]	[illegible]
55.7790	810.334	34.845	117.847
56.7790	721.022	34.846	117.845
[illegible]	[illegible]	[illegible]	[illegible]
58.7790	759.370	34.848	117.845
59.7790	74[illegible].383	34.849	117.838

SMOOTH DATA TAPE22

ELAPSED TIME(SEC)	VELOCITY FT/SEC	LAT (DEG)	LONG (DEG)
60.7790	746.077	34.850	117.836
[illegible]	[illegible]	[illegible]	[illegible]
62.7790	[illegible]	34.852	117.831
[illegible]	[illegible]	[illegible]	[illegible]
67.7790	753.357	34.853	117.823
[illegible]	[illegible]	[illegible]	[illegible]
75.7790	820.104	34.851	117.810
76.7790	842.242	34.850	117.810
[illegible]	[illegible]	[illegible]	[illegible]
79.7790	853.513	34.847	117.810
[illegible]	[illegible]	[illegible]	[illegible]

END OF RADAR PROCESSING

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT (continued)

COMBINED RADAR AND ADAS DATA

ENTERING COMBINE
MERGE ADAS TAPE9 & RADAR TAPE22 TO OUTPUT TAPE16

ELAPSED TIME(SEC)	FLIGHT NUMBER		LAT NAUMILES		LONG NAUMILES	RADIAL ERROR
SRAD=	.6088	SYSLAT=	2092.496	SYSLONG=	5804.869	
LRAD=	[illegible]	RLAT =	2092.401	RLONG =	5804.277	
.779	219		.096		.592	.599
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	.6087	RLAT =	2092.719	RLONG =	5805.432	
1.779	219		.012		.495	.495
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	.6087	RLAT =	2092.632	RLONG =	5804.987	
2.779	219		.099		.341	.355
SRAD=	[illegible]	SYSLAT=	2092.643	SYSLONG=	5805.024	
LRAD=	.6087	RLAT =	2092.[illegible]	RLONG =	5804.739	
3.779	219		.105		.286	.304
SRAD=	.6087	SYSLAT=	2092.[illegible]	SYSLONG=	5805.121	
LRAD=	.6087	RLAT =	2092.501	RLONG =	5804.835	
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
SRAD=	[illegible]	SYSLAT=	2092.401	SYSLONG=	5805.721	
LRAD=	.6087	RLAT =	2092.404	RLONG =	5804.992	
[illegible]	219		-.003		.720	.729
SRAD=	.6086	SYSLAT=	2092.319	SYSLONG=	5805.818	
LRAD=	[illegible]	RLAT =	2092.303	RLONG =	5805.150	
[illegible]	219		.016		.668	.668
SRAD=	.6086	SYSLAT=	2092.235	SYSLONG=	5805.915	
LRAD=	[illegible]	RLAT =	[illegible]	RLONG =	[illegible]	
7.779	219		.032		.617	.618
SRAD=	.6086	SYSLAT=	2092.[illegible]	SYSLONG=	5805.877	
LRAD=	[illegible]	RLAT =	2092.[illegible]	RLONG =	5805.449	
[illegible]	219		.036		.428	.432
SRAD=	.6085	SYSLAT=	2091.989	SYSLONG=	5806.071	
LRAD=	.6085	RLAT =	2091.[illegible]	RLONG =	5805.645	
[illegible]	219		.039		.426	.427
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	[illegible]	RLAT =	2091.834	RLONG =	5805.787	
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT (continued)

ELAPSED TIME(SEC)	FLIGHT NUMBER		LAT NAUMILES		LONG NAUMILES	RADIAL ERROR
[illegible]	219		.211		.293	.362
SRAD=	[illegible]	SYSLAT=	2090.913	SYSLONG=	5803.003	
LRAD=	[illegible]	RLAT =	[illegible]	RLONG =	[illegible]	
55.779	219		.189		-.000	.189
SRAD=	[illegible]	SYSLAT=	2090.914	SYSLONG=	5803.003	
LRAD=	[illegible]	RLAT =	2090.782	RLONG =	5802.830	
56.779	219		.136		.173	.220
SRAD=	[illegible]	SYSLAT=	2091.000	SYSLONG=	5803.061	
LRAD=	[illegible]	RLAT =	2090.838	RLONG =	5802.653	
57.779	219		.162		.389	.421
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	[illegible]	RLAT =	2090.394	RLONG =	5802.477	
58.779	219		.107		.159	.191
SRAD=	[illegible]	SYSLAT=	2091.083	SYSLONG=	5802.674	
LRAD=	[illegible]	RLAT =	2090.94[illegible]	RLONG =	5802.304	
[illegible]	[illegible]		.138		.370	.395
SRAD=	[illegible]	SYSLAT=	2091.165	SYSLONG=	5802.577	
LRAD=	[illegible]	RLAT =	2090.998	RLONG =	5802.130	
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
SRAD=	[illegible]	SYSLAT=	2091.165	SYSLONG=	5802.172	
LRAD=	[illegible]	RLAT =	2091.045	RLONG =	5801.961	
[illegible]	219		[illegible]		.211	.242
SRAD=	[illegible]	SYSLAT=	2091.244	SYSLONG=	5802.210	
LRAD=	[illegible]	RLAT =	[illegible]	RLONG =	5801.789	
[illegible]	219		.152		.421	.448
SRAD=	[illegible]	SYSLAT=	2091.244	SYSLONG=	5801.804	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
104.779	219		1.806		-4.641	4.980
SRAD=	[illegible]	SYSLAT=	2091.742	SYSLONG=	5796.761	
LRAD=	.6079	RLAT =	2089.935	RLONG =	5801.402	
105.779	219		1.806		-4.641	4.980
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	.6079	RLAT =	2089.935	RLONG =	5801.402	
106.779	219		1.806		-5.046	[illegible]
SRAD=	[illegible]	SYSLAT=	2091.324	SYSLONG=	5796.253	
LRAD=	.6079	RLAT =	2089.935	RLONG =	5801.402	
107.779	219		[illegible]		-5.143	[illegible]
SRAD=	.6085	SYSLAT=	2091.742	SYSLONG=	5796.490	
LRAD=	.6079	RLAT =	2089.935	RLONG =	5801.402	
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
SRAD=	.6085	SYSLAT=	2091.742	SYSLONG=	5796.085	
LRAD=	.6079	RLAT =	2089.935	RLONG =	5801.402	

ELAPSED TIME(SEC)	FLIGHT NUMBER		LAT NAUMILES		LONG NAUMILES	RADIAL ERROR
109.779	219		1.806		-5.317	5.619
SRAD=	[illegible]	SYSLAT=	2091.742	SYSLONG=	5796.220	
LRAD=	[illegible]	RLAT =	[illegible]	RLONG =	[illegible]	
110.779	219		-2.574		4.765	5.436
SRAD=	[illegible]	SYSLAT=	2091.742	SYSLONG=	[illegible]	
LRAD=	[illegible]	RLAT =	[illegible]	RLONG =	[illegible]	
111.779	219		-2.574		4.360	[illegible]
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	5795.718	
LRAD=	[illegible]	RLAT =	2094.203	RLONG =	5791.252	
112.779	219		-2.391		4.466	[illegible]
SRAD=	[illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]	
LRAD=	[illegible]	RLAT =	2094.183	RLONG =	5791.245	
113.779	219		-2.441		[illegible]	[illegible]
SRAD=	[illegible]	SYSLAT=	2091.[illegible]	SYSLONG=	5795.667	
LRAD=	[illegible]	RLAT =	2094.183	RLONG =	5791.290	
114.779	219		-2.559		[illegible]	[illegible]

END OF COMBINE

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT (continued)

DATA RECORDED ON NEW FLIGHT HISTORY FILE AFTER MERGING

[illegible]

THE FIRST RECORD OF OLD HISTORY FILE IS AN END-OF-FILE (TAPE11)

END-OF-FILE WRITTEN ON NEW MASTER (TAPE11)

[illegible]

PLOT SPECIFICATIONS

[illegible]

INPUT OPTIONS FOR SECOND FLIGHT

[illegible]

FIGURE 61 PROGRAM ERROR CHECK CARD INPUT (continued)

SMOOTHED DATA

SMOOTH DATA TAPE22

ELAPSED TIME(SEC)	VELOCITY FT/SEC	LAT (DEG)	LONG (DEG)
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
-10314.0000	0.000	0.000	0.000
10.7790	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

SMOOTH DATA TAPE22

ELAPSED TIME(SEC)	VELOCITY FT/SEC	LAT (DEG)	LONG (DEG)
60.7790	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
100.7790	[illegible]	[illegible]	[illegible]

END OF RADAR PROCESSING

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT (continued)

MERGED RADAR AND SYSTEM DATA

ENTERING COMBINE

MERGE ARAS TAPE9 & RADAR TAPE22 TO OUTPUT TAPE16

ELAPSED TIME(SEC)	FLIGHT NUMBER	LAT NAUTILES	LONG NAUTILES	RADIAL ERROR
10.779	219	SYSLAT= [illegible] RLAT = [illegible]	SYSLONG= [illegible] RLONG = [illegible]	[illegible]
11.779	219	SYSLAT= [illegible] RLAT = [illegible]	SYSLONG= [illegible] RLONG = [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FIGURE C1 PROGRAM NAVAN CHECK CASE INPUT (continued)

ELAPSED TIME(SEC)	FLIGHT NUMBER	LAT NAUMILES	LONG NAUMILES	RADIAL ERROR
64.779	219	.044	.004	.000
SRAD= .6095	SYSLAT=	2091.907	SYSLONG=	5788.290
LRAD= [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
65.779	219	.347	.347	.350
SRAD= .6095	SYSLAT=	2091.983	SYSLONG=	5788.026
LRAD= .6095	FLAT =	2091.867	ALONG =	5788.130
66.779	219	.122	.492	.507
SRAD= [illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]
LRAD= .6095	FLAT =	2091.877	ALONG =	5788.024
67.779	219	.030	.209	[illegible]
SRAD= [illegible]	SYSLAT=	[illegible]	SYSLONG=	[illegible]
LRAD= .6095	FLAT =	2091.384	ALONG =	5787.920
68.779	219	[illegible]	[illegible]	[illegible]
SRAD= .6095	SYSLAT=	2091.989	SYSLONG=	[illegible]
LRAD= .6095	FLAT =	2091.881	ALONG =	5787.846
69.779	219	[illegible]	[illegible]	[illegible]
SRAD= .6094	SYSLAT=	2091.907	SYSLONG=	5788.042
LRAD= .6095	FLAT =	2091.385	ALONG =	5787.730
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SRAD= .6095	SYSLAT=	2091.983	SYSLONG=	5787.932
LRAD= .6094	FLAT =	2091.387	ALONG =	5787.633
71.779	219	.100	.310	[illegible]
SRAD= .6095	SYSLAT=	2091.984	SYSLONG=	5788.087
LRAD= [illegible]	FLAT =	[illegible]	ALONG =	[illegible]
72.779	219	.101	.334	[illegible]
SRAD= .6095	SYSLAT=	2091.989	SYSLONG=	5787.817
LRAD= [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
73.779	219	.095	.397	.408
SRAD= .6095	SYSLAT=	2091.983	SYSLONG=	5787.817
LRAD= .6095	FLAT =	2091.897	ALONG =	5787.320
74.779	219	.092	.497	.505
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

END OF CORDING

DATA PLACED ON OLD HISTORY FILE FOR SECOND FLIGHT

TIME (SECONDS)	FLIGHT NUMBER	ERROR LATITUDE NAUMILES	ERROR LONGITUDE NAUMILES	RADIAL ERROR
10.779	219	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FIGURE C1   PROGRAM NAVAN CHECK CASE INPUT (concluded)

TIME (SECONDS)	FLIGHT NUMBER	ERROR LATITUDE NAUMILES	ERROR LONGITUDE NAUMILES	RADIAL ERROR
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
86.779	219	.356	.239	.268
91.779	219	.355	[illegible]	[illegible]
94.779	219	.343	.240	.491
96.779	219	.343	.246	.605
99.779	219	[illegible]	[illegible]	[illegible]
101.779	219	.332	.376	.577

THE FIRST RECORD OF OLD HISTORY FILE IS AN END-OF-FILE (TAPE17)

END-OF-FILE WRITTEN ON NEW MASTER (TAPE11)

TIME SLICE = .2000E+02
BEGIN TIME = 0.
STOP TIME = .1017E+03

SECOND FLIGHT PLOT SPECIFICATIONS

THE NUMBER OF PLOTS TO BE PLOTTED ARE 6 X-INTERVAL= 10.000 Y-INTERVAL= .500
2.000 7.000 2.000 3.000 0.000 0.000 0.000 3.003 0.000 0.003 0.000
XLEN 12.000 YLEN 8.000 YST -2.003
2 CHECK TWO

FIGURE C1   PROGRAM NAVAN CHECK CASE INPUT (concluded)

```
MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME =  16.78          NO. DATA POINTS= 20
  [illegible]
  .429809E+NA     .487482E+03     .100000E+01     .373759E+00     .462569E+00     .957476E+00     .647801E+00
  [illegible]
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  .977027E+02     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   .172992E+00AND   .647827E+00

II  =    20
IJ  =    .200000E+02
IJM1=    .190000E+02
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME =  30.78          NO. DATA POINTS= 21
  [illegible]
  .321135E+NA     [illegible]     .100000E+01     [illegible]     .340967E+00     .437531E+00     .531405E+00
  [illegible]
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  .478285E+00     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   [illegible]AND   [illegible]

II  =    21
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME =  51.78          NO. DATA POINTS= 21
  [illegible]                                                                                   .473390E+03
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  .413038E+00     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   [illegible]AND   [illegible]

II  =    21
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME =  77.78          NO. DATA POINTS= 21
  [illegible]                                                                                   .102594E+01
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  .111066E+01     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   [illegible]AND   [illegible]

II  =    21
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME =  93.78          NO. DATA POINTS= 21
  [illegible]                                                                                   .390728E+01
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  .421234E+01     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   [illegible]AND   [illegible]

II  =    21
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R             RMS             GV/RMS          P(1)            P(2)            P(3)            P(4)
R50             90C             CEP             90THP

TIME = 114.78          NO. DATA POINTS= 11
  [illegible]                                                                                   .829632E+01
92 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
85 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
65 PERCENT CONFIDENCE LIMITS FOR CEP ARE   [illegible](LOWER) AND   [illegible](UPPER)
  [illegible]     0.              0.              0.              0.              0.              0.
92 PERCENT CONFIDENCE LIMITS FOR P90TH ARE   [illegible]AND   [illegible]

II  =    11
[illegible]
```

FIGURE C2   PROGRAM NAVAN CHECK CASE OUTPUT

```
MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R            RMS             GM/RMS          P(1)            P(2)            P(3)            P(4)
R50             R9C             CEP             90THP

TIME =  20.78          NO. DATA POINTS= 10
 [illegible]
 .301368E+00     .357029E+03     .100003E+01     .215355E+00     .322926E+00     .421823E+00     .518064E+00
 [illegible]
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  .447556E+00(UPPER)
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  [illegible](UPPER)
[illegible]
 .476281E+00    0.             0.             0.             0.             0.             0.
90 PERCENT CONFIDENCE LIMITS FOR P90TH ARE  [illegible]AND  [illegible]

JJ   =     10
XJ   =     .100000E+02
XJM1 =     .900000E+01
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R            RMS             GM/RMS          P(1)            P(2)            P(3)            P(4)
R50             R90             CEP             90THP

TIME =  30.78          NO. DATA POINTS= 21
 [illegible]
 .408634E+00     .449201E+03     .100303E+01     .304398E+00     .408598E+00     .522549E+00     .632802E+00
 [illegible]
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  .950397E-01(LOWER) AND  .502235E+00(UPPER)
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  .983776E-01(LOWER) AND  .484849E+00(UPPER)
[illegible]
 .519700E+00    0.             0.             0.             0.             0.             0.
90 PERCENT CONFIDENCE LIMITS FOR P90TH ARE  [illegible]AND  [illegible]

JJ   =     21
XJ   =     .210000E+02
XJM1 =     .200000E+02
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R            RMS             GM/RMS          P(1)            P(2)            P(3)            P(4)
R50             R9C             CEP             90THP

TIME =  51.79          NO. DATA POINTS= 21
 [illegible]
 .375263E+00     .444033E+03     .100303E+01     .364360E+00     .439413E+00     .515446E+00     .621736E+00
 [illegible]
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  .447223E+00(UPPER)
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  [illegible](UPPER)
[illegible]
 .520669E+00    0.             0.             0.             0.             0.             0.
90 PERCENT CONFIDENCE LIMITS FOR P90TH ARE  [illegible]AND  [illegible]

JJ   =     21
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R            RMS             GM/RMS          P(1)            P(2)            P(3)            P(4)
R50             R9C             CEP             90THP

TIME =  72.78          NO. DATA POINTS= 21
 [illegible]
 [illegible]     [illegible]     .100003E+01     [illegible]     .414623E+00     .520645E+00     .617473E+00
 [illegible]
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  .501078E+00(UPPER)
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  [illegible](UPPER)
[illegible]
 .935031E+00    0.             0.             0.             0.             0.             0.
90 PERCENT CONFIDENCE LIMITS FOR P90TH ARE  [illegible]AND  [illegible]

JJ   =     21
XJ   =     .213000E+02
[illegible]

MEAN LAT        SIGMA LAT       MEAN LONG       SIGMA LONG      MEAN R          SIGMA R
MEDIAN R            RMS             GM/RMS          P(1)            P(2)            P(3)            P(4)
R50             R9C             CEP             90THP

TIME =  93.78          NO. DATA POINTS= 19
 [illegible]
 .437922E+00     .478251E+03     .100303E+01     .332921E+00     .430272E+00     .535020E+00     .666641E+00
 [illegible]
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  .537770E+00(UPPER)
95 PERCENT CONFIDENCE LIMITS FOR CEP ARE  [illegible](LOWER) AND  [illegible](UPPER)
[illegible]
 .547877E+00    0.             0.             0.             0.             0.             0.
90 PERCENT CONFIDENCE LIMITS FOR P90TH ARE  [illegible]AND  [illegible]

JJ   =     19
XJ   =     .190000E+02
XJM1 =     .180000E+02
[illegible]
```

FIGURE C2   PROGRAM NAVAN CHECK CASE OUTPUT (concluded)

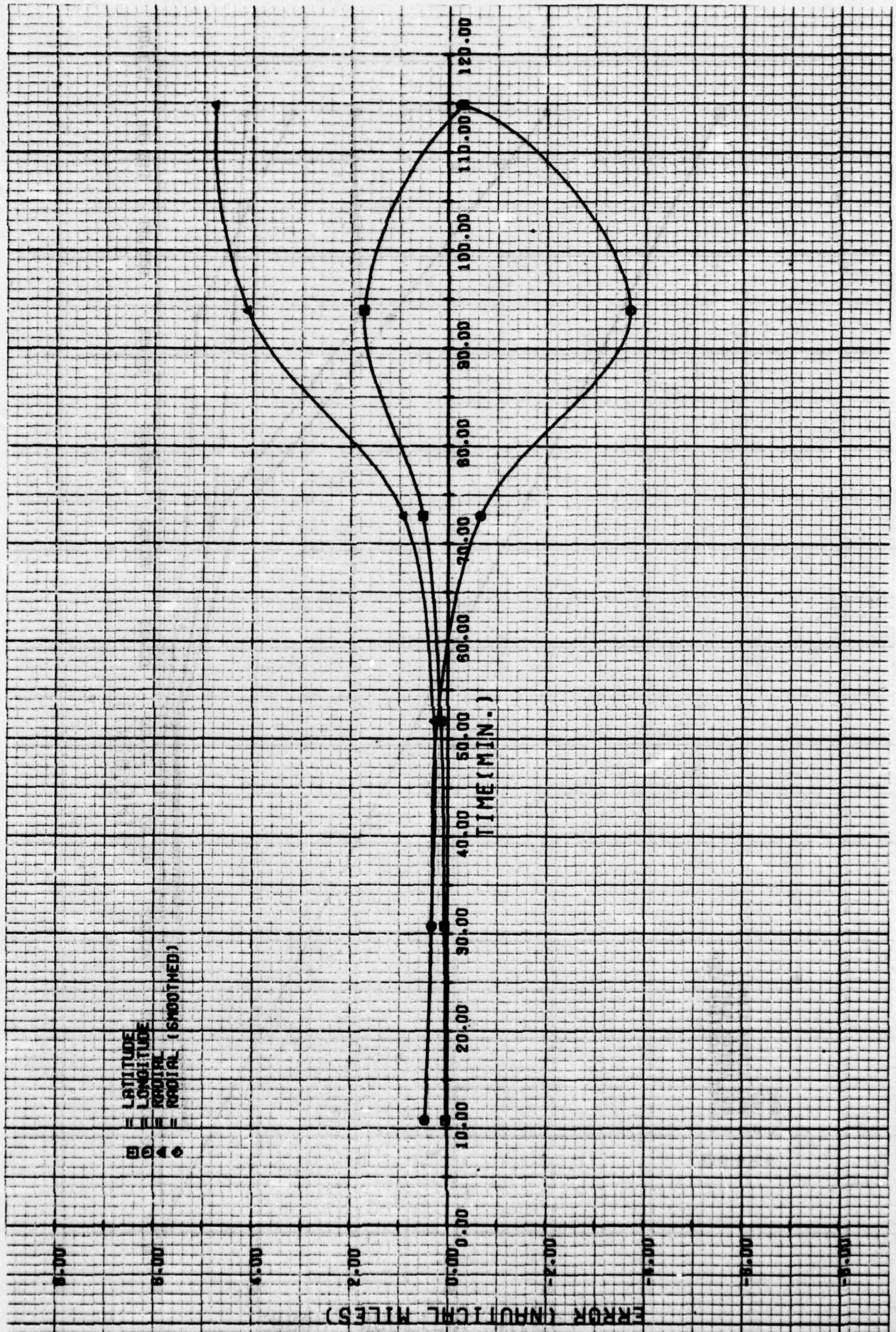


FIGURE C3 PROGRAM NAVAN CHECK CASE PLOT NO. 1

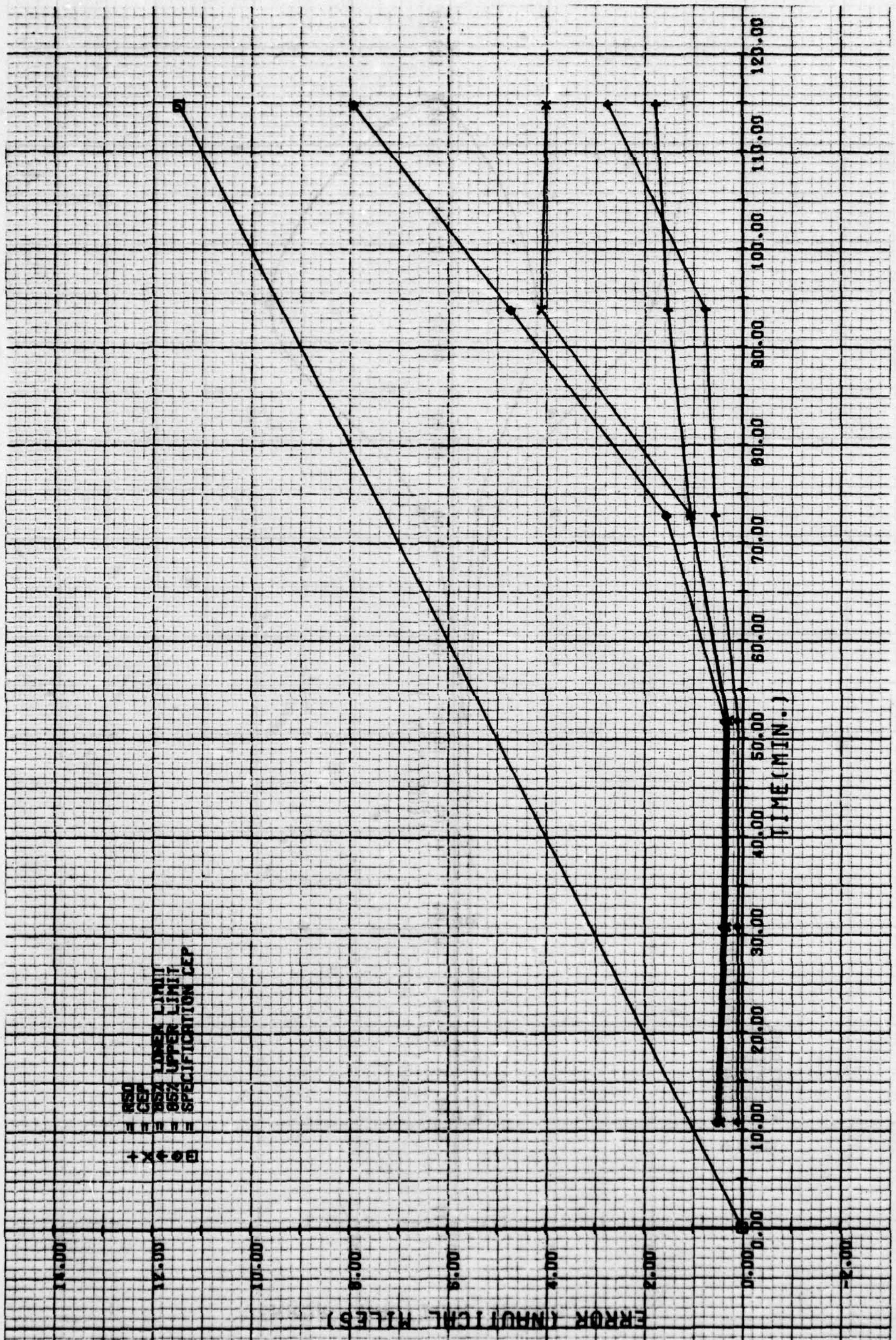


FIGURE C4 PROGRAM NAVAN CHECK CASE PLOT NO. 2

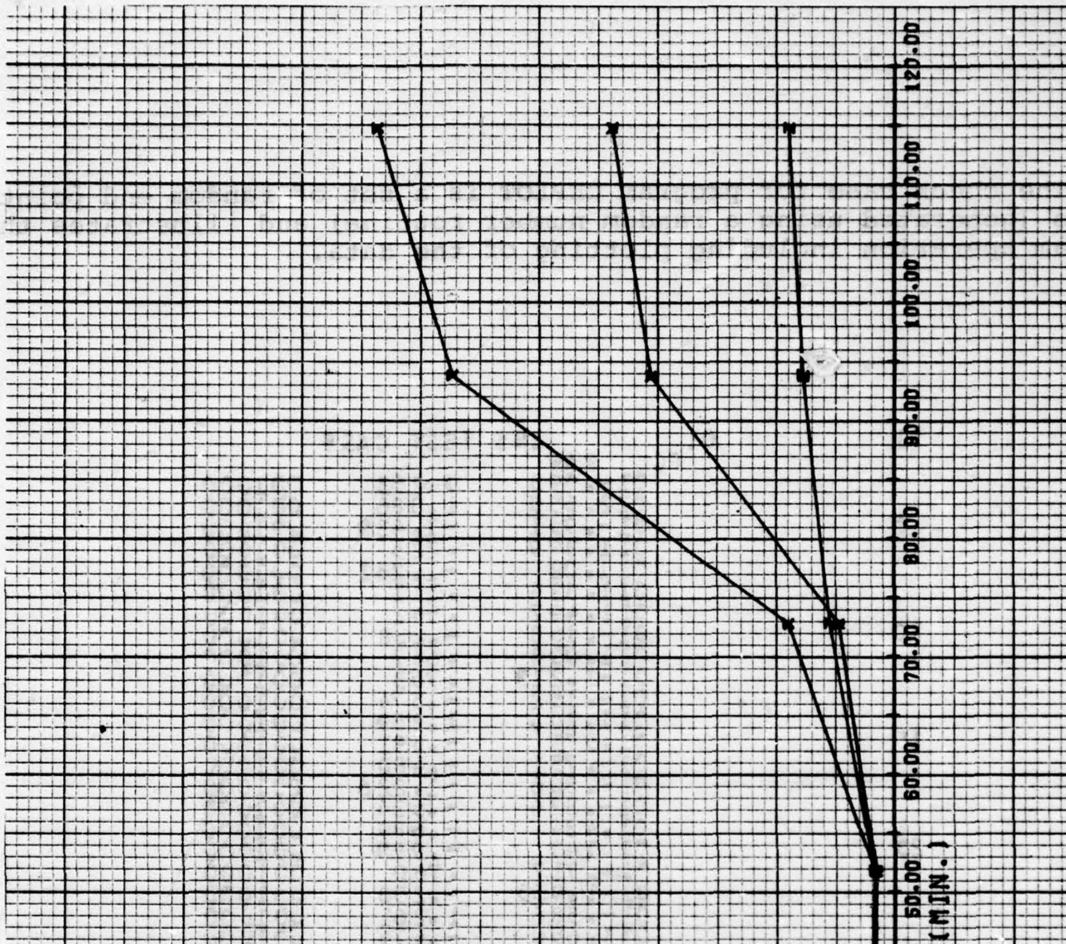


FIGURE C5 PROGRAM NAVAN CHECK CASE PLOT NO. 3

The check case for program CEPLOT is a set of random end point errors (generated using a random number routine) and illustrates the program operation including plotting of the data.

```
01              INS TEST CASE
   GC      RAW
      01-.995       0.253        001000
      012.555       1.086        001000
      01-.951       -1.430       001000
      011.399       .225         001000
      011.02        -1.281       001000
      011.324       .111         001000
      011.497       .542         001000
      01-.168       -.238        001000
      011.038       .687         001000
      01-1.213      .753         001000
      01-.152       -.574        001000
      011.100       1.259        001000
      01.575        -.591        001000
      01-.751       -.480        001000
      01-.806       -1.226       001000
      01-.324       -.534        001000
      01.439        -.689        001000
      01.143        -.980        001000
      01-.717       .760         001000
      01-1.955      -.258        001000
      01-.586       1.261        001000
      011.650       -.474        001000
      011.015       -.019        001000
      01-1.337      1.700        001000
      01.190        1.400        001000
      01-.821       -.711        001000
      01.580        .249         001000
      01-.936       -.851        001000
      01-1.316      .217         001000
      01-1.019      1.009        001000
         END "ABSENT"
```

FIGURE C6 PROGRAM CEPLOT CHECK CASE INPUT

TERMINAL DATA FOR 4 GC ALIGNMENT

FLT NO		TERMINAL DELTA LAT (NM)	TERMINAL DELTA LONG (NM)	ELAPSED TIME (HR)		NORMALIZED DELTA LAT (NM)		NORMALIZED DELTA LONG (NM)		NORMALIZED RADIAL (NM)
01		-.095	.253	1.000		-.095		.253		.270
	1	.27025E+00	.10000E+01	-.095	.253	.270	0.000	0.000	0.000	
01		2.555	1.066	1.000		2.555		1.066		2.776
	2	.75027E+00	.10000E+01	2.460	1.339	3.046	0.000	0.000	0.000	
01		-.951	-1.430	1.000		-.951		-1.430		1.717
	3	.12885E+01	.10000E+01	1.509	-.091	4.764	0.000	0.000	0.000	
01		1.399	.225	1.000		1.399		.225		1.417
	4	.18257E+01	.10000E+01	2.906	.134	6.18[illegible]	0.000	0.000	0.000	
01		1.020	-1.281	1.000		1.020		-1.281		1.637
	5	.29896E+01	.10000E+01	3.928	-1.147	7.818	0.000	0.000	0.000	
01		1.324	.111	1.000		1.324		.111		1.329
	6	.39722E+01	.10000E+01	5.252	-1.036	9.147	0.000	0.000	0.000	
01		1.497	.542	1.000		1.497		.542		1.592
	7	.63241E+01	.10000E+01	6.749	-.494	10.739	0.000	0.000	0.000	
01		-.168	-.238	1.000		-.168		-.238		.291
	8	.18423E+01	.10000E+01	6.581	-.732	11.030	0.000	0.000	0.000	
01		1.008	.687	1.000		1.008		.687		1.220
	9	.22474E+01	.10000E+01	7.589	-.045	12.250	0.000	0.000	0.000	
01		-1.213	.753	1.000		-1.213		.753		1.428
	10	.32086E+01	.10000E+01	6.376	.708	13.676	0.000	0.000	0.000	
01		-.152	-.574	1.000		-.152		-.574		.594
	11	.19052E+01	.10000E+01	6.224	.134	14.272	0.000	0.000	0.000	
01		1.100	1.259	1.000		1.100		1.259		1.672
	12	.31852E+01	.10000E+01	7.324	1.393	15.944	0.000	0.000	0.000	
01		.575	-.591	1.000		.575		-.591		.825
	13	.26264E+01	.10000E+01	7.899	.802	16.768	0.000	0.000	0.000	
01		-.751	-.480	1.000		-.751		-.480		.891
	14	.25409E+01	.10000E+01	7.148	.322	17.659	0.000	0.000	0.000	
01		-.806	-1.226	1.000		-.806		-1.226		1.467
	15	.34346E+01	.10000E+01	6.342	-.904	19.127	0.000	0.000	0.000	
01		-.324	-.534	1.000		-.324		-.534		.625
	16	.21453E+01	.10000E+01	6.018	-1.438	19.751	0.000	0.000	0.000	
01		.439	-.689	1.000		.439		-.689		.817
	17	.17526E+01	.10000E+01	6.457	-2.127	20.968	0.000	0.000	0.000	
01		.143	-.980	1.000		.143		-.980		.990
	18	.17356E+01	.10000E+01	6.600	-3.107	21.559	0.000	0.000	0.000	
01		-.717	.760	1.000		-.717		.760		1.045
	19	.15136E+01	.10000E+01	5.883	-2.347	22.603	0.000	0.000	0.000	
01		-1.955	-.258	1.000		-1.955		-.258		1.972
	20	.35763E+01	.10000E+01	3.928	-2.605	24.575	0.000	0.000	0.000	
01		-.586	1.261	1.000		-.586		1.261		1.391
	21	.49729E+01	.10000E+01	3.342	-1.344	25.966	0.000	0.000	0.000	
01		1.650	-.474	1.000		1.650		-.474		1.717
	22	.59372E+01	.10000E+01	4.992	-1.816	27.663	0.000	0.000	0.000	
01		1.015	-.019	1.000		1.015		-.019		1.015
	23	.86668E+01	.10000E+01	6.007	-1.837	28.698	0.000	0.000	0.000	
01		-1.337	1.700	1.000		-1.337		1.700		2.163
	24	.13744E+02	.10000E+01	4.670	-.137	30.861	0.000	0.000	0.000	
01		.190	1.400	1.000		.190		1.400		1.413
	25	.26483E+02	.10000E+01	4.660	1.263	32.273	0.000	0.000	0.000	
01		-.821	-.711	1.000		-.821		-.711		1.086
	26	.23762E+02	.10000E+01	4.039	.552	33.359	0.000	0.000	0.000	
01		.580	.249	1.000		.580		.249		.631
	27	.18154E+02	.10000E+01	4.619	.801	33.991	0.000	0.000	0.000	
01		-.936	-.851	1.000		-.936		-.851		1.265
	28	.22966E+02	.10000E+01	3.683	-.050	35.256	0.000	0.000	0.000	
01		-1.316	.217	1.000		-1.316		.217		1.334
	29	.30631E+02	.10000E+01	2.367	.167	36.589	0.000	0.000	0.000	
01		-1.019	1.009	1.000		-1.019		1.009		1.434
	30	.43926E+02	.10000E+01	1.348	1.176	38.023	0.000	0.000	0.000	

1	.046	.020	.045	.039
2	1.142	6.320	.045	.039
3	[illegible]	7.312	.045	.039
4	3.335	9.[illegible]45	.045	.039
5	5.077	10.396	.045	.039
6	5.093	11.732	.045	.039
7	5.335	13.641	.045	.039
8	5.412	13.886	.045	.039
9	5.532	14.813	.045	.039
10	6.341	16.390	.045	.039
11	6.717	16.435	.045	.039
12	8.205	17.548	.045	.039
13	8.613	17.629	.045	.039
14	9.872	18.462	.045	.039
15	10.473	19.186	.045	.039
16	10.891	19.323	.045	.039
17	11.332	19.478	.045	.039
18	12.370	19.467	.045	.039
19	12.990	20.068	.045	.039
20	13.978	24.068	.045	.039
21	14.471	24.466	.045	.039
22	14.734	27.042	.045	.039
23	14.738	27.983	.045	.039
24	17.496	29.093	.045	.039
25	19.348	29.914	.045	.039
26	19.911	30.664	.045	.039
27	[illegible]	[illegible]	.045	.039
28	20.747	31.912	.045	.039
29	20.779	33.764	.045	.039
30	21.719	34.896	.045	.039

R50= 1.297 CEP= .625 CEPR= 1.329 S Y= 1.079 S X= .851 SY/SX= 1.268 SRAD= .593

CEP1= 1.191 CEP2= 1.136

SUM X= 1.176 X MEAN= .039 SUM X SQ= 21.719

SUM Y= 1.348 Y MEAN= .045 SUM Y SQ= 34.896

MEAN RADIAL= 1.267

FIGURE C7 PROGRAM CEPLOT CHECK CASE OUTPUT

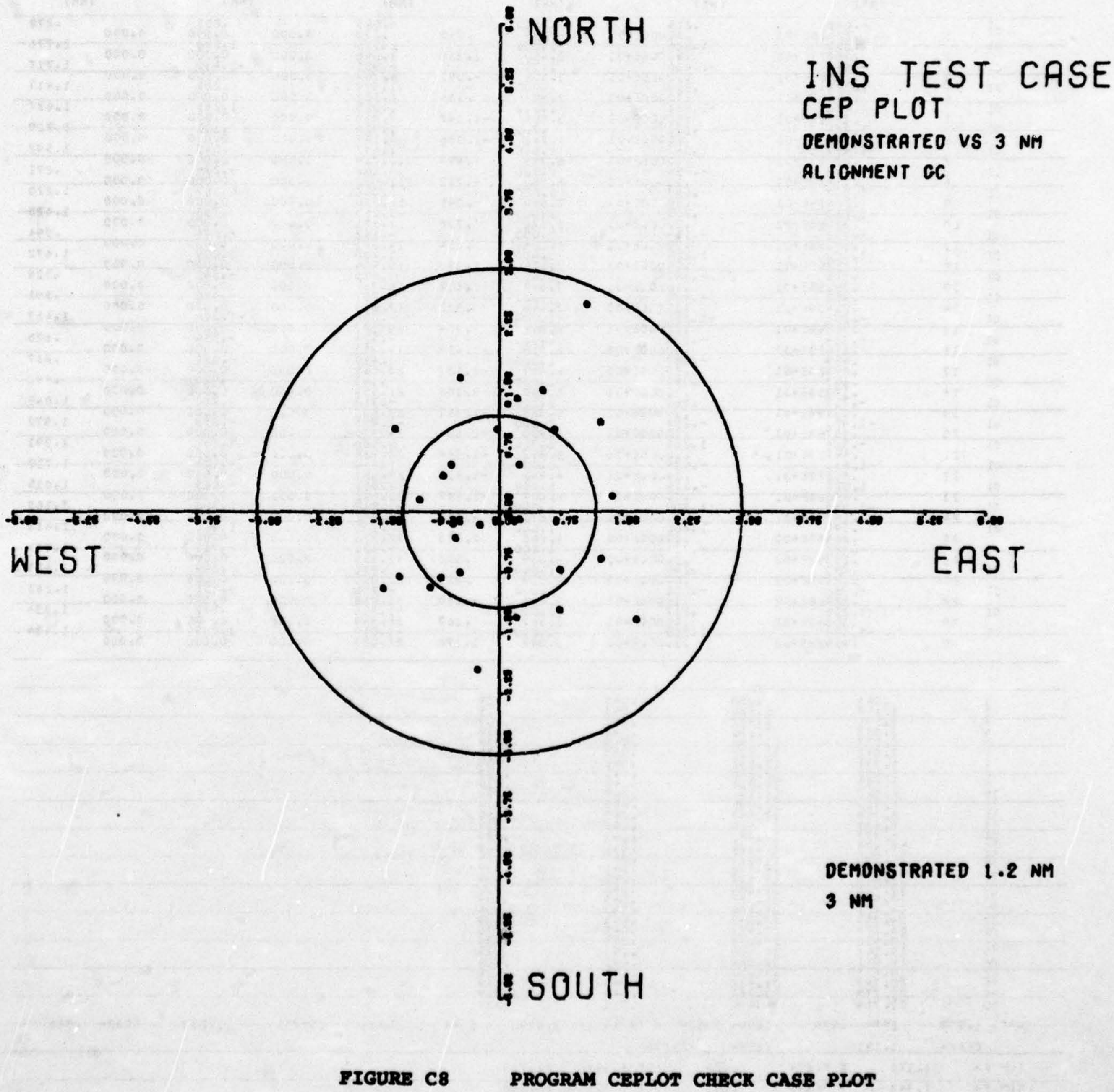


FIGURE C8 PROGRAM CEPLOT CHECK CASE PLOT

GLOSSARY

anisoelasticity	elastic deformation of a gyro's gimbals that result in gyro drift proportional to the g^2 value of vibration.
azimuth	horizontal direction or bearing.
azimuth angle	azimuth measured from 0° at the north or south reference direction clockwise or counterclockwise through 90° or 180°.
chi distribution test	a statistical significance test based on frequency of occurance.
circle of equal probability (CEP)	a measure of the accuracy with which an aircraft can be guided; the radius of the circle at a specific distance in which 50 percent of navigation errors fall; also called circular error probable, and circle of probable error.
cross coupling	The position of the accelerometer pendulum is off null by a small angle in order to create the error signal necessary to rebalance the accelerometer. This angle causes cross-coupling of the component of acceleration which is normal to the accelerometer.
geometric mean	a measure of central position. The geometric mean of n quantities equals the nth root of the product of the quantities.
heading	horizontal direction in which an aircraft is pointed, expressed as angular distance from a reference direction.
inertial coordinate system	a system in which the (vector) momentum of a particle is conserved in the absence of external forces. Thus, only in an inertial system can Newton's Laws of Motion be appropriately applied.
latitude	Terrestrial latitude is angular distance from the Equator, measured northward or southward through 90°.
longitude	Terrestrial longitude is the arc of a parallel, or the angle at the pole, between the prime meridian and the meridian of a point on the Earth, measured eastward or westward from the prime meridian through 180°.

magnetic pole	either of the two places on the surface of the Earth where the magnetic dip is 90°, that in the Northern Hemisphere (at, approximately, latitude, $73^{\circ}8'$N, longitude, 101°W in 1955) being designated North Magnetic Pole, and that in the Southern Hemisphere (at, approximately, latitude, 68°S, longitude, 144°E in 1955) being designated South Magnetic Pole.
proportional bias	the bias required to prevent gyro drift that results from acceleration perpendicular to the output axis at the gyro.
root mean square error (RMS)	in statistics, the square root of the arithmetic mean of the squares of the deviations of the various items from the arithmetic mean of the whole, also termed standard deviation.
Student's t distribution test	a statistical method to test the hypothesis that the mean of the sample is consistant with being equal to the mean, μ, of the assumed population.
vibropendulous	the accelerometer error produced when the pendulous mass in an accelerometer is vibrated. This error is proportional to the vibropendulous coefficient times this vibration in feet per second per second.

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Definition	Unit
a	acceleration	ft per sec^2
a_c	centripetal acceleration	ft per sec^2
d	distance	NM or ft
E	East	- - -
g	acceleration of gravity at mean sea level	32.3 ft per sec^2
GM	geometric mean	dimensionless
i	(subscript) test, $i = 1, m$	dimensionless
L	confidence limits	dimensionless
m	number of tests	dimensionless
N	North	- - -
q	a variable	dimensionless
$\bar{q}$	sample mean of q	dimensionless
r	radius of the Earth	2.09×10^7 ft
r	radial error $= \sqrt{x^2 + y^2}$	NM
RATIO	GM/RMS	dimensionless
R_p	pth percentile of radial error	dimensionless
S	South	- - -
t	time	sec
t	t in Student's t test	- - -
T.O.	Technical Order	- - -
v	velocity	ft per sec
W	West	- - -
x	latitude error	NM
y	longitude error	NM
z	vertical	- - -
z_p	pth percentile point of a zero mean normal distribution	dimensionless

Item	Definition	Unit
α	$(1-\alpha)$% confidence intervals	dimensionless
δ_a	azimuth drift rate	deg per hr
ε_a	acceleration error	ft per sec^2
ε_d	distance error	NM or ft
ε_ℓ	level gyro drift rate	deg per hr
ε_v	velocity error inside the Schuler loop	ft per sec
ε_{vo}	velocity error outside the Schuler loop	ft per sec
ε_σ	azimuth angle error	deg
ε_θ	pitch angle error	deg
ε_ϕ	roll angle error	deg
θ	pitch angle	deg
λ^2	g/r	1/sec^2
μ_q	mean or expected value of q	dimensionless
s	sample sigma	dimensionless
$s_q^{\ 2}$	sample variance of q	dimensionless
σ	azimuth angle	deg
$\sigma_q^{\ 2}$	variance of q	dimensionless
Σq_i	sum of q_i for i = 1, m	dimensionless
Φ	latitude	deg
ϕ	roll angle	deg
χ	chi	dimensionless
ψ	gyro torquing rate	deg per hr
Ω	Earth rotation rate	15.04 deg per hr
ω	radians per unit time	rad per hr